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SAGINAW BAY: AN EVALUATION OF EXISTING AND HISTORICAL CONDITIONS

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The water quality in Saginaw Bay has deteriorated from its natural Lake Huron character through man's overburdening use. Both the physical-chemical and biological characteristics indicate deteriorating conditions and trends. The intent of this report has been to compile and evaluate existing information on Saginaw Bay and document its present status. Water quality and trophic status have been evaluated with regard to physical, chemical, and biological parameters. Efforts were made to identify the community structure of aquatic plant and animal populations. Further emphasis has been placed on the identification and nature of water-quality variations and trends and the impact of contaminant sources on the system.

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SAGINAW BAY: AN EVALUATION OF EXISTING AND HISTORICAL CONDITIONS

by

Paul L. Freedman

THE UNIVERSITY OF MICHIGAN
GREAT LAKES RESOURCE MANAGEMENT PROGRAM

In fulfillment of

EPA Contract No. 68-01-1577

for the

ENVIRONMENTAL PROTECTION AGENCY
Region V

Great Lakes Initiative Contract Program
Report Number: EPA-905/9-74-003

EPA Project Officer: Howard Zar

This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provisions of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

This report has been reviewed by the Enforcement Division, Region V, Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorcement or recommendation for use.

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Summary and Conclusions

The water quality in Saginaw Bay has deteriorated from its natural Lake Huron character through man's overburdening use. Both the physical-chemical and biological characteristics indicate similar conditions and trends.

Chemically, Saginaw Bay is blighted by high concentrations of dissolved solids originating from the Saginaw River system. Concentrations are generally higher in the inner bay. A decreasing gradient exists outward as the Lake Huron water dilute their content. Distributions of the concentrating ions in bay surface waters tend to follow the flow of the contaminating Saginaw River as it is guided into the inner bay by the changing winds. Chloride ions exhibit a severe breach of natural water quality with average concentrations in the inner bay over fivefold those of the background Lake Huron values. Other ionic concentrations including potassium, sodium, calcium, and magnesium and other indicators such as conductivity and alkalinity suggest the same phenomena.

Excessive nutrient concentrations are also characteristic of Saginaw Bay. Both nitrogen and phosphorous are in sufficient levels to support prolific growths of algae. Total phosphorous concentrations are over four times those of Lake Huron. The distribution of phosphorous (and potassium) exhibits high concentrations originating from the Saginaw River, as do other ions, and remains predominantly in the more coastal regions of the inner bay. However, a tongue of low phosphorous concentration water extends through the central portions of the bay, and higher concentrations are also often noted along coastal regions in the outer bay. This suggests significant sources of runoff from all land areas surrounding the bay and interaction with the sediments in the shallower waters.

Chemically, the system's major contaminant source is the Saginaw River. Other tributary and industrial sources add what is usually considered to be minor contamination, except in the local environment. Questions now arise as to the significance of other sources with regard to nutrient concentrations.

Overall, the data is insufficient to quantitatively document any changes in bay quality with time. The available data does suggest, however, the the bay water quality may have been deteriorating up until the 1950's with slight improvements beginning in the 1960's. These conclusions are very speculative and were drawn from limited information.

The biologic communities of Saginaw Bay also are indicative of poor water quality. The deterioration and change in the biologic community can be attributed to primarily two factors. One is the change in water quality. The organisms respond to this by producing a community that is best suited for the now altered environment. The second is the invasion of new species to the system. Their predation and direct competition for the available food supply cause alterations in the biologic communities.

The existing benthic fauna of the bay indicate stressed and pollutional conditions. The pollution tolerant oligochaetes are the dominant group in the bay, demonstrating exceptionally high numbers in the inner bay. Population density distribution of oligochaetes is governed by bottom type and water quality. Their high opulation may be a result of their adaptability to low dissolved oxygen levels and high rates of sediment deposition. In the outer bay, amphipods predominate with a depth regulated distribution. Midges are also common. These two organisms generally prefer more dissolved oxygen and a thinner sediment layer, such as is found outside of the inner bay.

Overall, the benthic fauna of the bay indicate decreased environmental quality, particularly in the inner bay. Indicative evidence includes the increase in oligochaete predominance, the decrease in clean water types, and the disappearance of the once common mayfly population.

Saginaw Bay's fish community has also been heavily altered, particularly in the last half century. The commercial fishing industry has been severely curtailed. Species composition has changed dramatically to low value fish, and fish production has steadily decreased to its present low. Lake trout, walleye, whitefish, and lake herring once represented the bay's major resources; today they are scarce. Carp and yellow perch now compose the majority of the commercial catch. Causes for these changes include changes in the foodweb, predation and competition from invading marine sea lamprey and alewives, changes in habitat, commercial fishing exploitation, and changes in water quality.

Saginaw Bay is also subject to excessive algal growths. Phytoplankton concentrations are eight times the value normally found in Lake Huron, while carbon fixation rates were fifteen to thirty times greater. Ceratium is the dominant genera, although Microcystis and Aphanizomenon are common. Diatom populations were not found to be common although the only significant survey was taken during the summer months.

Numerous other serious problems exist in the bay but are not quantitatively documented by water-quality data. The problem of siltation has continually been termed severe and the associated problems of turbidity and sediment deposition affect water quality. The list of causative factors includes river and bay dredging, shoreline erosion, excessive algal growths, wind deposition of soils, and wave action churning up the sediments.

Thermal enrichment is also considered by many to be a potential problem. Thermal contamination from the Saginaw River (municipal and industrial discharges, particularly from power plants) has prompted these concerns. Disruption or destruction of the normal biological cycles is feared and adverse effects have already been noted in localized areas.

Occasional oil and chemical spills have been reported resulting in fish and wildlife mortality and fish tainting.

Water supply problems have also been realized. Filter clogging, taste and odor, and corrosion are among the major concerns.

Recommendations for Future Work

Despite Saginaw Bay's prominence as a natural resource, insufficient work has been performed on monitoring its water quality. The data is often inadequate to authoritatively document trends in water quality, both spatially and temporally. With the institution of the federal NPDES discharge system and efforts by federal, state, county, and municipal governments as well as industry to improve wastewater treatment, the degree of contamination to Saginaw Bay could change significantly in future years. The present array of information is grossly inadequate to predict any changes in bay water quality. Numerous important questions posed are now unanswerable. For example, if municipal and industrial discharges were forced to conform to increased phosphorous or nitrogen removal programs, what would be the effects on water quality? How would the concentrations in the bay change? Would productivity and algae concentrations decrease? Would they fall to acceptable levels? How would changes in algal concentrations change turbidity and, consequently, reflect on its own productivity? Would decreases in primary productivity affect fish populations? What would be the difference in effects between a local versus regional program? Using only the present array of information available on the bay, such questions cannot even begin to be answered. It is for these reasons that intensive limnological monitoring and modeling programs are recommended. The application of such models would allow us to make accurate predictions of answers to the various questions posed. It would enable us to assess the effects of new water-quality standards and enforcement programs. The relative importance of various contaminant sources to the bay water quality could be quantitatively evaluated. Thus, future decisions regarding discharge requirements and water-quality management could be rationally established.

The institution of any predictive methodology necessitates large amounts of water-quality data for verification. An unverified model is of no value. Presently, the necessary data for verification does not exist. Physical and chemical parameters have been comprehensively sampled only once, and that occurred over 17 years ago. Since then the bay has been sampled; however, typically no more than six stations were involved. (One possible exception to this is the chloride data, periodically collected by Dow Chemical Co.). The availability of biologic information on the bay is slightly better. The benthic resources have been adequately documented. The fish resources have been satisfactorily reported by the U.S. Department of Interior Fish and Wildlife Service; however, emphasis has been placed only on the commercial fisheries. Also, only limited information is available on the spatial distribution of fish. Plankton and productivity information is presently severely limited. No relevant comprehensive survey exists. Because of these inadequacies, the following recommendations are made so as to allow application of existing predictive methodologies for water-quality management.

A two-year synoptic survey should be instituted for the bay similar to the 1956 survey reported by Beeton et al. (1967). Sampling should encompass the entire bay at surface and subsurface levels. This information is necessary to determine subsurface circulation and its relation to surface conditions. All such information would be valuable in establishing a verified Saginaw Bay circulation model, a requisite for all modeling efforts. Thus far only qualitative information is available concerning the circulation; much more needs to be known. The sampling program should also place particular emphasis on obtaining information from shallow waters, an area that has been largely neglected in earlier studies.

Full nutrient analysis should be performed routinely, including all forms of nitrogen, phosphorous, and silicon. Such complete information is presently not available from any one survey.

Other standard limnological parameters must also be routinely measured. Trace metals analysis should be carried out on a limited basis to establish its relative importance and document any violation of standards.

In respect to biologic sampling, plankton information is needed. A year-round sampling program of both phytoplankton and zooplankton should be instituted. Complete taxonomic identification studies are essential. Measurements should also include total productivity and carbon and nitrogen fixation rates.

The benthic resources of the Saginaw Bay have already been satisfactorily documented; the most recent comprehensive study having been carried out in 1967. Limited additional studies should only be carried out to evaluate recent changes in the communities and document local environmental effects.

The fish resources of the bay have also been heavily monitored. The continued examination of fish communities should be left up to the appropriate governmental agencies. Limited fish studies may be needed and are recommended in localized pollution troubled areas.

Emphasis in the sampling study should include not only open water stations but especially coastal stations near contaminant sources. Monitoring should be carried out at the mouths of all discharging rivers and outlets for industrial discharge.

Further work also needs to be done on the Saginaw River. Although sufficient data is available at the river's mouth, very limited data exists at upstream stations. Monitoring of the entire length of the river should be instituted. This would facilitate accurate evaluation of individual contaminant sources from within its watershed.

It should be noted here that these are only general suggestions; the actual number, distribution, and frequency of the sampling program should be made compatible with the specific requirements of any modeling effort.

Modeling applications should be directed toward evaluation of existing or potential problems identified within the bay; the prominent concerns being high dissolved solids, excessive nutrient and phytoplankton concentrations, thermal enrichment, turbidity and siltation, and coliform bacterial conditions.

I. Introduction

The Saginaw Bay region (Figure 1) has been recognized as a highly productive and valuable ecosystem. It facilitates a mixture of outstanding recreation, prosperous industries, and some of Michigan's best agriculture. It still, though, maintains a significatn population of aquatic and terrestrial wildlife. In recent years, some attention has been focused on the area pointing to decreased environmentla quality and a loss in potential for resource utilization. Particular emphasis has been on the bay itself and its tributary system. These claims have been prompted by such factors as an increase in bay water salinity, decrease in commercial and recreational fish production, an excess of algal growths, and changes in fish and benthic faunal species. Man's overburdening use of the region's resources and his oversightedness with regard to preserving it may have been one cause. The clarification and documentation of these claims has been the impetus of this study.

The intent of this project has been to compile and evaluate existing information on Saginaw Bay and document its present status. Water quality and trophic status have been evaluated with regard to physical, chemical, and biological parameters. Efforts were made to identify the community structure of aquatic plant and animal populations. Further emphasis has been placed on the identification and nature of water-quality variations and trends and the impact of contaminant sources on the system.

To attain these objectives, the appropriate governmental agencies and scientific journals were surveyed to collect all relevant information. An enumeration and synopsis of these efforts is in appendixes A and B, and includes a list of all

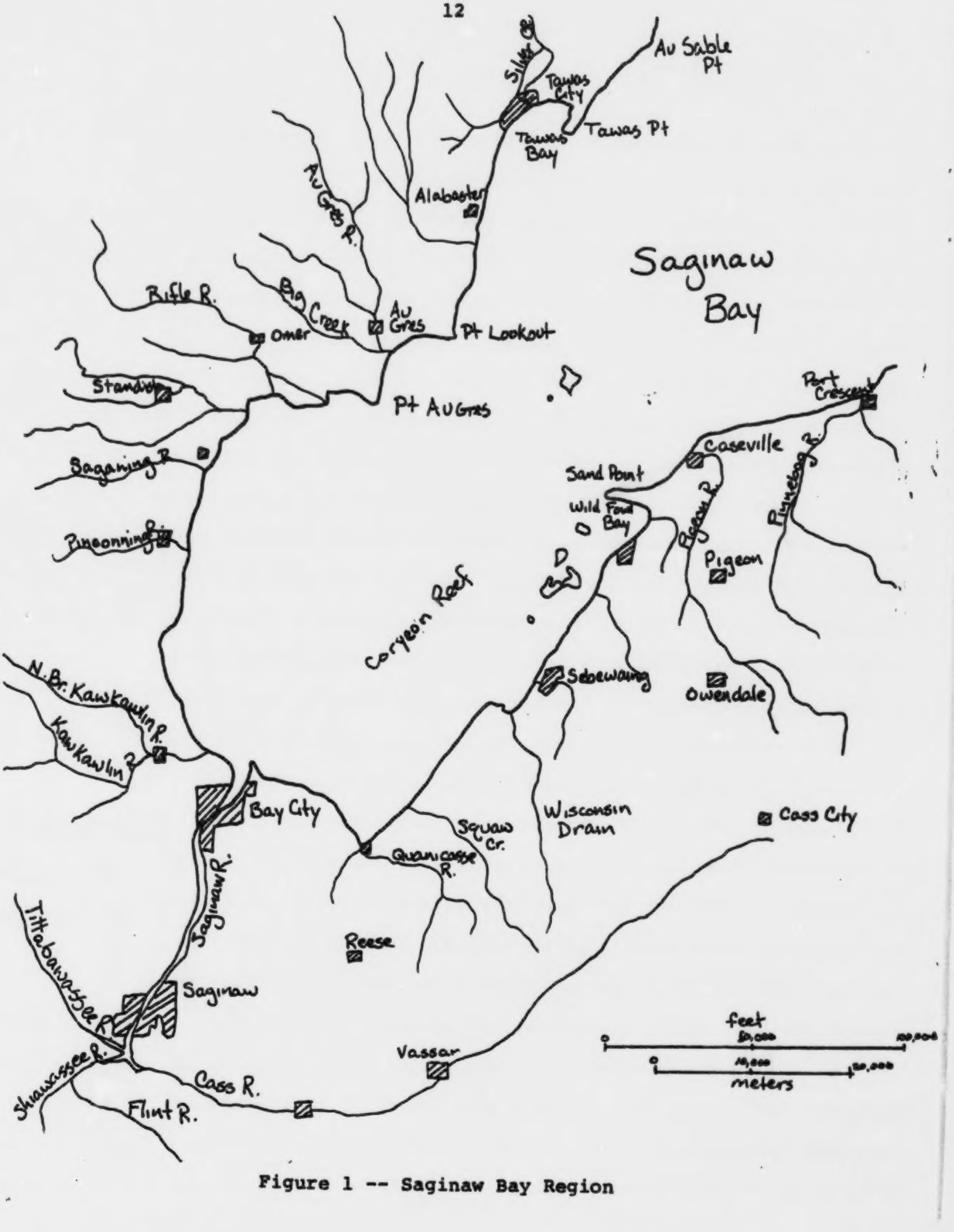


Figure 1 -- Saginaw Bay Region

agencies and persons contacted and an annotated bibliography of the information obtained.

II. Geographical and Industrial Setting (Geomorphology of the Basin and Its Features)

Saginaw Bay is an inland extension of the western shore of Lake Huron, projecting southwesterly midway into the southern peninsula of Michigan. This shallow arm is 26 miles (42 km) wide at its mouth between Point Aux Barques and Au Sable Point and approximately 51 miles (82 km) long, measured from the Saginaw River to the outer entrance of the bay. The bay narrows to a minimum width of 13 miles (21 km) between Lookout Point and Sand Point. At this constriction, a broad shoal from Charity Island to Sand Point divides the bay into what is termed the inner and outer bay. The bay's 1,143 square miles (2,960 km^2) of surface area are equally divided between the inner and outer bay (Figure 2). The inner or southern zone is much shallower, having a mean depth of 15 feet (4.6 m) and maximum depth of 46 feet (14.0 m), as compared with the outer bay's mean depth of 48 feet (14.6 m) and maximum depth of 133 feet (40.5 m). As a result, the inner bay contains only 30% of the total bay water volume. Calculated on a volume basis, 57.1% of the total bay has a depth of 24 feet or less while 34.2% has a depth of 12 feet or less. (Beeton et al., 1967).

Within the bay there are several islands. The most prominent include the Charity Islands, located in the center of the bay, and several lowlying marsh-surrounded islands, located south of Sand Point (South, Stony, and Katechay).

Shore character variation is moderate. The western shores of the outer bay are primarily sand with a few rocky outcrops near Point Lookout. The eastern shores north of Sand Point are sandy,

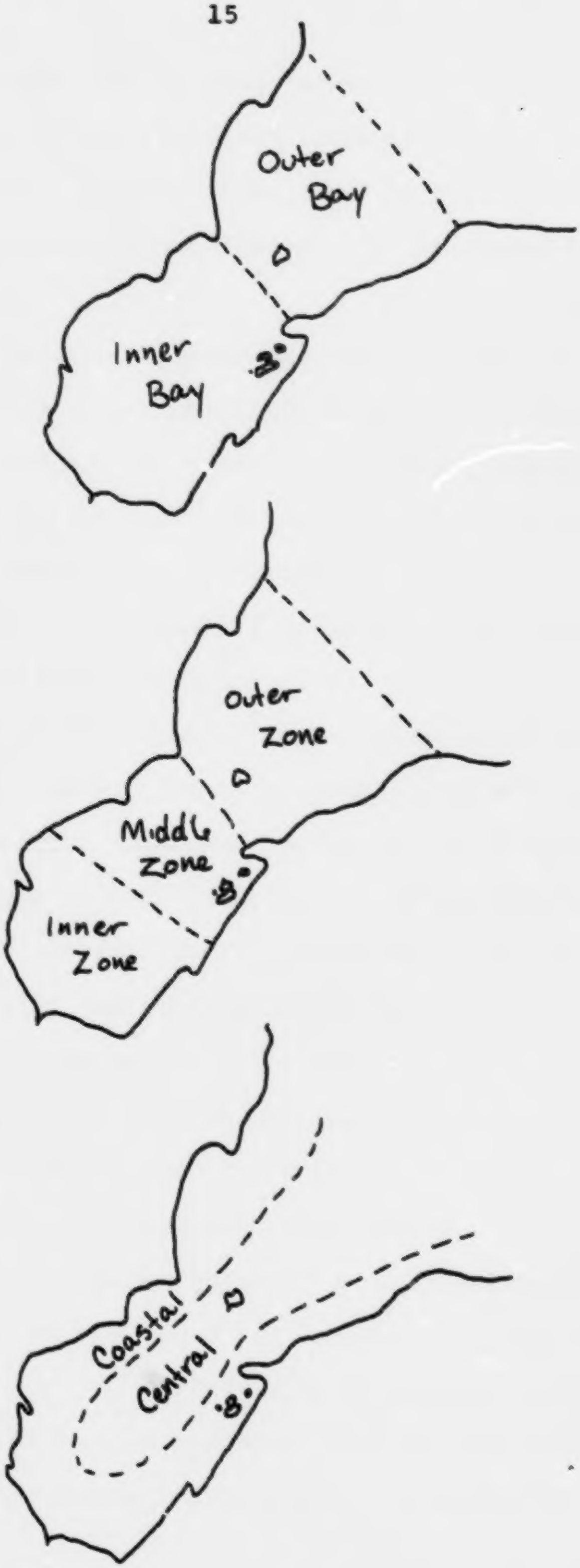


Figure 2 -- Saginaw Bay Area Divisions
as Discussed Within the Text.

grading rapidly into rocky shores east of Hat Point. South of Sand Point and around to Lookout Point the shore areas vary from predominantly marsh to low, sandy ridges. North of Lookout Point the shores are primarily sandy with occasional rock upcroppings.

Geologically, Saginaw Bay has been considered a shallow extension of Lake Huron. Following the final retreat of the Pleistocene Ice, the Saginaw Bay region was covered by glacial Lake Saginaw. As the lake receded to its present boundaries, it exposed lucastrine sediments which are marked by today's sand beaches. The bay cuts into a large formation of bedrock primarily from the Mississippian and Pennsylvanian periods. It is unlikely, however, that these preglacial rocks contributed significantly to the present sediment structure of Saginaw Bay. Most of these sediments have been removed by currents, and bare rock has been exposed by wave action. The Pleistocene glacial till that today define the majority of the bay bottom. These deposits of quartz, sand, gravel, and silt have by now been locally shifted and sorted by bay currents. Extensive sandy flats exist south of Wildfowl Bay and west from the Saginaw River to Point Au Gres. An extensive reef area, Coryeon Reef, exists from Charity Islands south to just north of the Quinicassee River mouth. It is a gravel and sand bar with a ridge of 6 feet (1.8 m) and is separated from shore by water of a depth greater than 10 feet (3.2 m). Overall, the inner bay is dominated by extensive shallows (Beeton et al., 1967).

Today, land usage in the bay's basin is diverse. Agriculture is the major land consumer, encompassing approximately 50% of total basin acreage (Kimball and Bachman, 1969). Of this, the majority is cropland. In contrast, only 3.5% of the land is urbanized, and yet the area still commands a significant industrial network -- the automobile, chemical, mining, and food industries are the most prominent. Although only 1.2% of the land areas are designated for recreation, 34.2% of the region is still considered forested. These lands, the marshlands, and other undeveloped acreage possess significant wildlife resources. The area supports numerous aquatic and terrestrial fur animals, upland game and white-tailed deer, and is a nationally known waterfowl preserve. The basin supported an estimated population of 1,235,920 in 1970, demonstrating a growth of 15.9% over 1960.

III. Hydrology

Four basic hydrologic factors control the net supply of water to Saginaw Bay: runoff (drainage), precipitation, ground water flow, and evaporation. Saginaw Bay receives drainage from a basin seven times larger than the bay itself or over 8000 square miles (5.12 million acres or approximately 21,000 km^2). Of this drainage, the major source is the Saginaw River Basin, drawing from 6,222 square miles of land, nearly 80% of the total bay's basin. The major tributary rivers of the bay and their drainage characteristics are listed in Table 1.

The majority of the watershed is covered with Podzol-type soils, similar in organic character. The degree of soil compaction or tightness differs considerably, though. Depending on the soil structure, precipitation can either percolate quickly and easily or run off. The flow characteristics, then, of each of the tributaries can differ considerably, and generalizations concerning flow stability cannot be made. More will be said concerning each tributary in the following chapter on contaminant sources, as each river will be discussed separately.

The average annual water levels in Saginaw Bay are controlled by the Lake Huron water level and, hence, are a function of water inflow from Lake Superior and Lake Michigan, outflow through St. Clair River, and annual climatology. Within a one-year period the monthly average lake levels do not vary much from the summer high levels to the winter low levels (Corps Eng., 1952). The bay water level can, though, demonstrate very short-term, rapid, and large fluctuations as a result of wave runup, wind driven tides,

Table 1: Major River Drainage to Saginaw Bay

River and Station Locations	Total Drainage Area sq m	Dates of Records	Average Flow cfs	Momentary Max Flow cfs	Minimum DailyFlow cfs	Limited Flow Info cfs
Au Gres R	420					
(at National)	(169)	50-present	97.5 (21 yrs)	2350	5.9	
East Branch Au Gres R						
(at McIvor)	(84)	50-present	63.8 (21 yrs)	1310	22	
Kawkawlin R	224					
(at mouth)	(224)	65-present		2575	0	
Pigeon R	156					
(near Pigeon)	(86)	46-52	64.2 (5 yrs)	3700	0	
(near Owendale)	(55)	52-present	28.0 (19 yrs)	2550	.1	
Pine R	99					
(by Standish)		none	calculated estimate- - - - - - - - - - -			56
Pinnebog R	171					
(at Oliver)		none	calculated estimate- - - - - - - - - - -			30
Rifle R	387					
(near Lupton)	(56.8)	56-71	91.7 (21 yrs)	1330	48	
(at Selkirk)	(117)	50-present	143 (21 yrs)	2760	55	
(20 miles from mouth)	(320)	36-present	306 (35 yrs)	5340	75	
Saginaw R*	6222					
1) Cass R	931					
(at Cass)	(370)	47-present	190 (24 yrs)	8460	.5	
(at Wahjamego)	(637)	68-present		7610	22	ave≅400
2) Flint R	1300					
(near Otisville)	(531)	52-present	259 (19 yrs)	6150	4.3	
(near Flint)	(954)	32-present	533 (39 yrs)	14900	9	
(near Fosters)	(1120)	39-present	668 (27 yrs)	19000	27	
3) Shiawassee	1160					
(at Linden)	(81.2)	67-present		262	2.8	
(at Byron)	(368)	47-present	237 (24 yrs)	2900	3.55	
(at Owosso)	(538)	31-present	310 (40 yrs)	6240	2	
4) Tittabawassee	2620					
(at Midland)	(2400)	36-present	1569 (35 yrs)	34000	111	
Chippewa						
(near Midland)	(597)	47-present	424 (24 yrs)	8510	44	

(Table 1 cont'd)

5) Saginaw Sebewaing	149 110	42-present*				

*Information available only during high water due to unusual hydraulic characteristics of the River.

Additional direct bay tributaries not listed include: Quinnacassee River, Saganing River, Silver Creek, Squaw Creek, Wiscoggin Drain, and White Feather Creek.

Compiled from the following sources:
1. Environmental Protection Agency STORET Data retrieval system 1973 retrieval.
2. USGS Water Resources Data for Michigan Part 1, Surface Water Records 1971.
3. U. S. Dept. Interior. National Estuary Study, Vol. 3, 1970.
4. Water Resource Commission, Michigan DNR, Interim Water Quality Management Plan for Saginaw River and Huron Western Shore Minor Basins, April 1971.

seiches, etc. According to the Great Lakes Pilot (1956), "The Saginaw Bay is subject to sudden changes in wind. A northern gail can drive water into the bay so as to raise the level at the mouth of the Saginaw River 3 to 4 feet in less than as many hours, while a southwest wind lowers the level at times sufficient to cause large vessels to run aground in the channel." High bay water levels have at times created significant shore erosion problems. In 1951 the Corps of Engineers (1952) estimated $150,000 damage in the area from Bay City to Port Huron and $1,268,500 damage from Bay City to the Straits of Mackinac which included Alpena Bay as the only significant beach erosion area outside of Saginaw Bay. This shore erosion results not only in property damage but contributes to water-quality degradation. The eroded shore material increases turbidity and adds unoxygenated mass to the water-sediment system.

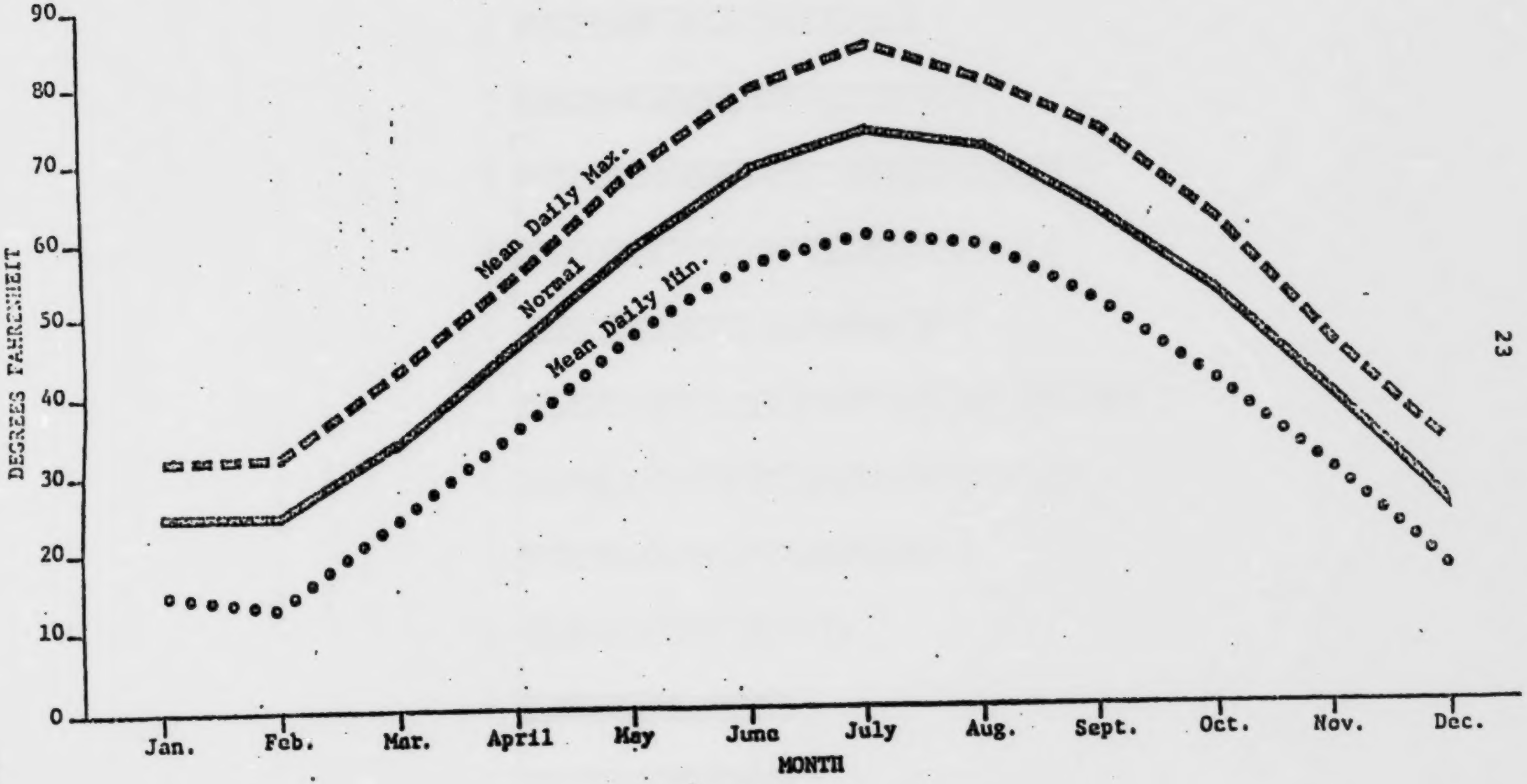
Saginaw Bay undergoes the usual annual temperature cycle experienced by most fresh water, temperate zone lakes. The deep water temperatures remain at or near the point of maximum density, 4° C (39° F) year-round. The shallow and surface waters, though, undergo thermal change from season to season. In the spring the total water mass warms from 1° C to 4° C and produces a vertically homothermous condition. Thereafter, the shallow waters tend to warm more quickly, the degree depending on local conditions. Only in the outer reaches of the bay does a well-formed thermocline persist in the summer and fall; although, temporary stratification does occur within the bay during the summer. Complete winter ice cover and limited stratification is typical of the bay during winter months. Ice forms in December and usually deteriorates by March.

Because of the bay's mid-continent, mid-latitude location, it is subject to weather conditions. The weather is moderated slightly due to the obvious "lake effect." The bay lies in the pathway of storms that sweep across the Great Lakes region from west to southwest. The result is frequent and, at times, rapid weather changes, extreme seasonal variation in temperature, and a fairly even annual distribution of precipitation (Figures 3 and 4). The mean yearly temperature is 8.35°C (47° F). The summer months experience a mean maximum temperature of 27.5° C (81.4° F) and a mean minimum temperature of 14.6° C (58.3° F).

The winter months are dominated by the colder Canadian air masses resulting in slightly less precipitation and humidity. Low temperatures can drop well below zero. The average snowfall is 102.6 cm, 40.4 inches (Figure 5), with the ground freezing to a depth of .3 to 1 (1 to 3 feet). The average frost-free season is only 150 days (May to early October).

The annual precipitation (mean 74.6 cm, 29.4 inches) is well distributed throughout the year with monthly averages ranging from 3.6 cm (1.44 inches) in January to 8.2 cm (3.23 inches) in June (See Figure 4).

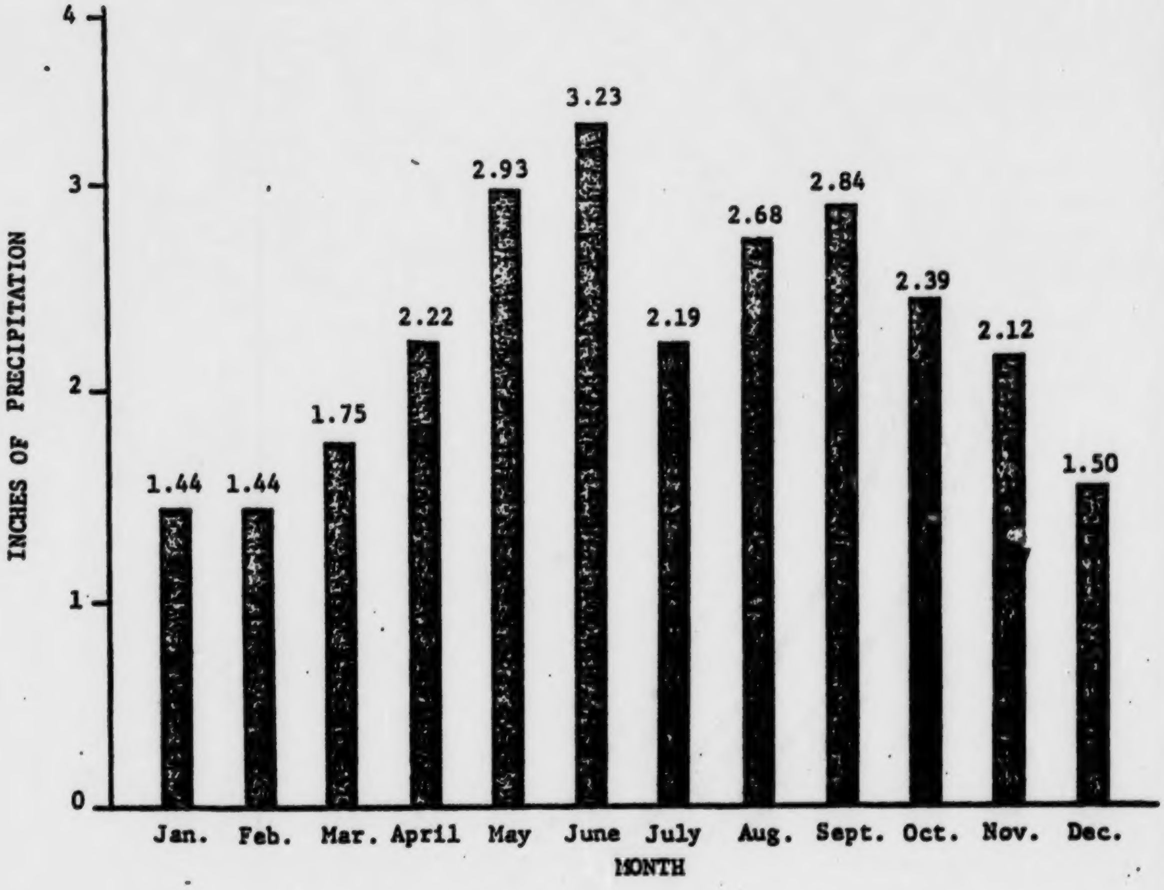
The winds principally originate from the WSW and SW directions with the least common wind directions being east (Figure 6). The prevailing westerlies have a mean speed of 15 to 20 kph (9.4 to 12.5 mph). The highest mean wind speeds occur during March when the most frequent WSW winds average 24.8 kph (15.5 mph).



Monthly Mean Temperature at the
Bay City Sewage Plant, Bay City, Michigan.

(Sixty- three Year Period of Record)

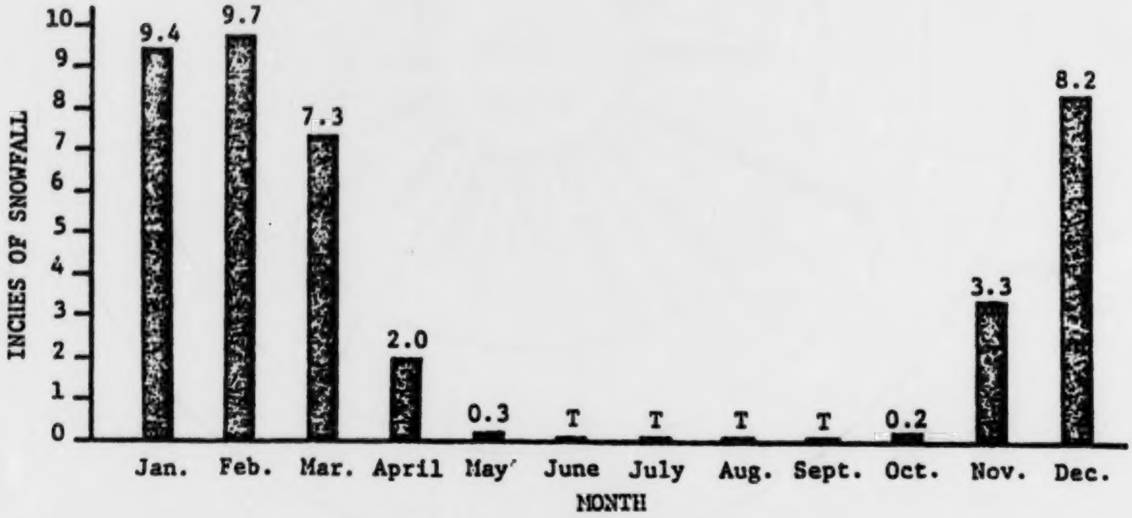
Figure 3 source: Consumers Power 1972



Mean Total Monthly Precipitation at the
Bay City Sewage Plant, Bay City, Michigan.

(Sixty-four Year Period of Record)

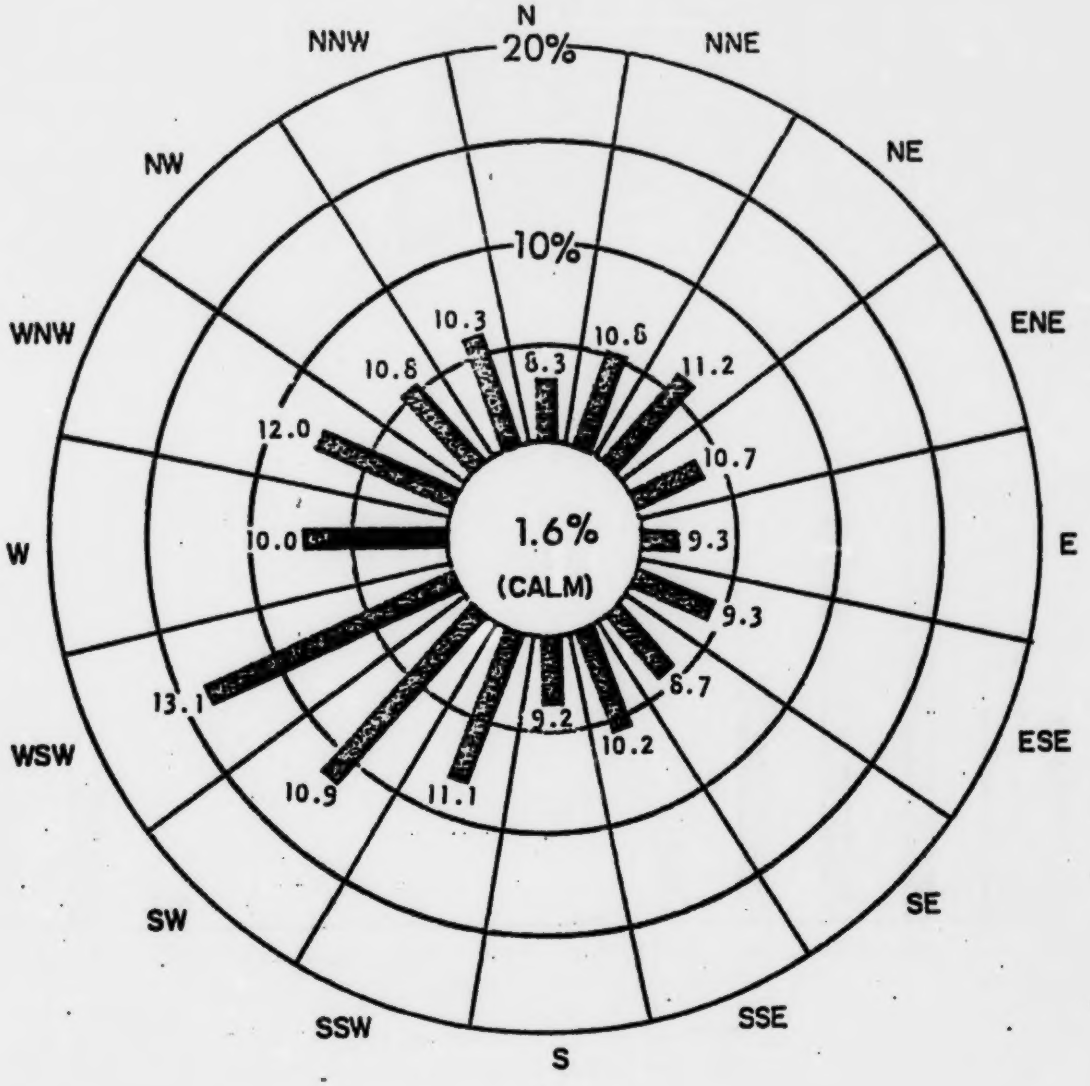
Figure 4 source: Consumers Power 1972



Monthly Mean Snowfall at the
Saginaw Airport, Saginaw Michigan.

(Sixty-three Year Period of Record)

Figure 5 source: Consumers Power 1972



Average Annual Wind Speed=10.6 MPH

LEGEND

8.3 Average speed for sector in miles per hour

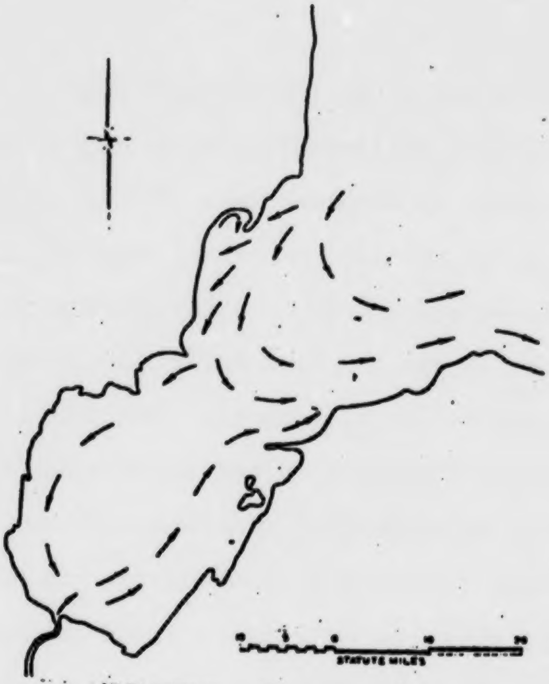
▨ Vector length indicates frequency of occurrence in sector (percent)

SAGINAW, MICH. ANNUAL
WIND ROSE
(1949-1953)

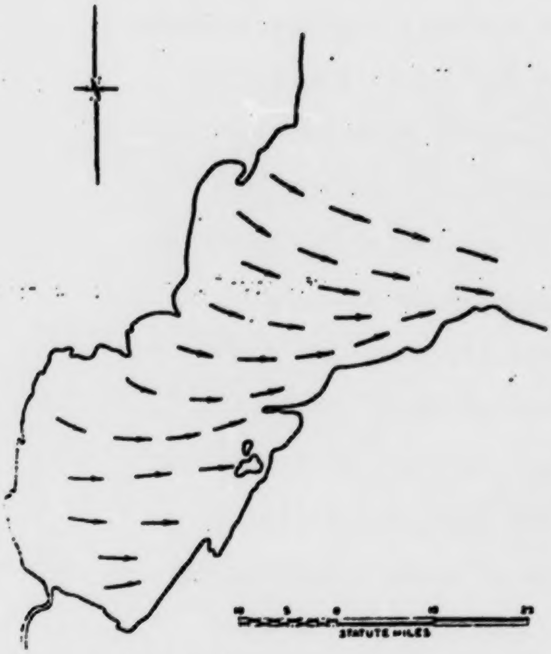
Figure 6 source: Consumers Power 1972

Wind conditions, along with the strong Lake Huron circulation, play prominent roles in determining the highly variable water circulation conditions in Saginaw Bay. The prevailing circulation is speculated to be counterclockwise, typical of a northern estuary. Lake Huron waters enter from the northeast flow along the bay's north shore, while the Saginaw River flow hugs the southern shore and then exits to Lake Huron. The prevailing west and southwest winds and the rotation of the earth tend to reinforce speculation on this circulation. Surface currents tend to be closely related to wind conditions, reorienting their directions with respect to changing winds in relatively short periods of time. Because of the relative shallowness of the bay and its limited stratification, it is suspected that subsurface currents are highly influenced by surface flow.

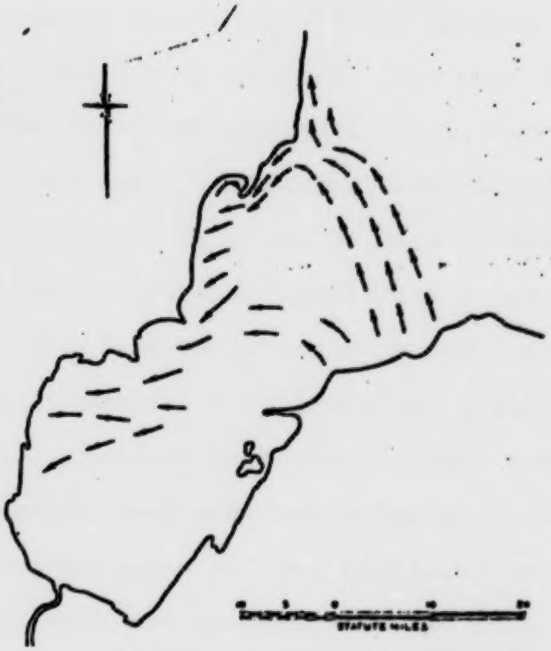
Johnson (1958) carried out extensive surface current studies on Saginaw Bay. In 1956, 2,650 drift bottles were released in Saginaw Bay and adjacent waters of Lake Huron. From the recovery results Johnson concluded, "that the dynamics of the bay are closely related to the highly variable meteorological conditions and that the surface currents are in a continuous state of change. For this reason we must state specifically under what conditions any particular surface currents pattern was found." Johnson further demonstrated that although surface currents did at times resemble what has been termed the typical currents, no pattern persisted over an extended period of time. Completely different current patterns could exist depending on the wind characteristics (See Figure 7). Johnson further documented the strong influence of currents entering the bay from Lake Huron



--Typical surface-current flow for Saginaw Bay in the summer of 1956.



.--Surface currents in Saginaw Bay determined from travel of drift bottles released on August 10, 1956, during a period of moderate westerly winds.



.--Surface currents in Saginaw Bay determined from travel of drift bottles released on October 12-13, 1956, during a period of strong southeast-northeast winds.

Figure 7 source: Johnson 1956

which could, on occasion, override the wind-induced conditions. Johnson made no attempt to study subsurface current, although he did speculate a close dependence of subsurface flow on surface currents.

Chloride surveys by the Michigan Stream Control Commission in 1935 and 1936 (Adams, 1937) provided good examples of how current flow tends to follow wind patterns (Beeton et al., 1967). By following the high chloride discharge of the Saginaw River, possible current patterns can be derived. The predominant northeasterly winds of May 12-24, 1935 were followed by clockwise circulation, as indicated by the surveys of May 13-19 and May 20-24, 1935. A similar clockwise circulation could be seen in the survey of June 22-25 due to the north, northeast, and southeast winds. Counterclockwise circulations resulted from westerly winds as documented by the winds of June 19-28, 1935 and the surveys of June 24-28 and July 1-4. From the data it appeared that the bay circulation could change from a clockwise to a counterclockwise circulation in as little as 4 days. Beeton further documented the influence of the Coriolis effect on the Saginaw River. After entering the bay, the river waters tended to deflect to the right, as indicated by the higher ion concentrations along Coryeon Reef, the southeast shore of the inner bay, and the south shore of the outer bay. During the winter, ice-covered Saginaw River flow was unaffected by the winds and tended to also show a northeasterly flow and subsequent ion buildup, as shown by the March 1936 chloride surveys.

Ayers et al. (1956), although primarily concerned with Lake Huron circulation, was able to draw some conclusions concerning

Saginaw Bay circulation from their studies. They suggested that the bay had a typical counterclockwise circulation with spring inflow along the northern shore of the bay mouth and outflow along the southern shore, with both inflow and outflow extending from surface to bottom. In the summer the outflow appeared to be spread out over the surface of the entire mouth while the inflow was subsurface. This change from horizontal to vertical circulation is typical of estuaries of similar geographic location. They speculated that with the fall breakdown of the thermocline the system would revert to a horizontal circulation, and remain as such till the following summer. This since has been neither confirmed nor disproved. Further studies concerning the subsurface currents are merited. Presently E. C. Monahan and A. W. Green at The University of Michigan are developing a detailed mathematical model of the Saginaw Bay circulation. It was not complete at the time this article was written.

Beeton et al. (1967), using data from their 1956 survey, calculated flushing times for the bay. Only the Saginaw River was considered in the calculations because at the time of the study all other direct river discharges to the bay amounted to only 8% of the flow of the Saginaw River and each also had significantly lower ion concentrations. Flushing times were calculated by taking the ratio of accumulated river water in the estuary to the volume introduced daily. Chloride content was used to differentiate between the natural lake water and the more saline river water. They calculated flushing times for the inner, middle, and outer zones of the bay on three dates, representing the spring, summer, and fall. The corresponding total flushing times were 114 days, 280 days, and 376 days, with an average of 186 days. Flushing time increased with decreasing flow, the effect being more pronounced in the inner bay. Specific figures and detailed comparisons cannot, however, be relied upon because of variations in river flow and ion content. Lakeward transport calculations were also performed demonstrating, as expected, a decrease with decreasing river discharge.

These hydrologic examinations of the interactions between the Saginaw River and the Saginaw Bay do not, however, reflect the actual complexity of the system. Depending on the wind conditions, barometric pressure distribution, and lake level, the Saginaw River flow at times can reverse, allowing bay water to flow inland. This phenomenon can introduce much complexity and error into any analysis made. More concerning this flow reversal will be presented in the section concerning the Saginaw River.

IV. Contaminant Sources

The Saginaw River

The Saginaw River is the major contaminant source to Saginaw Bay. Its basin of 6,222 square miles is the largest in the state, although it drains only 246 square miles directly. The 22-mile river is formed at the junction of the Shiawassee and Tittabawassee Rivers with the Cass and Flint Rivers having entered the Shiawassee slightly upstream. Cheboygaining and Dutch Creeks also flow into the river at intermediate points downstream, draining 100 and 40 square miles respectively. The river enters the bay at the southwestern end.

The river has been dredged and used extensively as a commercial waterway. This has not, however, prevented its other multifaceted uses, including fishing, power development, irrigation, water supply, and park development. Well over one-third of the land usage in the basin is devoted to agriculture, yet it still includes highly industrialized urban areas such as Saginaw, Flint, Midland, and Bay City. Other large areas in the basin are occupied by state and federal game sanctuaries.

The Saginaw is a slow-moving river, having a gradient of 1 foot per mile or less its entire length. At drought flows (350 cfs) velocities can get as low as .03 feet per second.

Stream flow records for Saginaw River are only available during periods of high water. The river has unusual hydraulic characteristics. Its level will change as much as 3 feet in a year and on occasion significant level changes can take place within a few hours as a result of the raising or lowering of Saginaw Bay by northeasterly or southwesterly winds. These changes can cause flow reversals whose effects can at times even be observed in the river's tributaries. Flow reversals occur on 85% of the days, last typically for 3 to 9 hours, and can be caused by as little as 1/10 foot change in river height. The reversals do not effect the long-term time of passage but their significance lies in the doubling and tripling of pollutional loads to the river as it stops, reverses, stops, and then resumes its original course. (Time of passage-dye studies, flow reversal-gauge studies and drought severity studies have been carried out by the Michigan Water Resource Commission [WRC].)

As a result of the river's unusual character, stream flows are usually calculated by adding the flows of its tributaries and other discharge sources. The flows typically range from 500 to 8000 cfs throughout a year with a median value estimated grossly as 1700 cfs and an average of 3850 cfs.

The Saginaw River receives both municipal and industrial discharges. Five municipalities discharge their treated wastes into the Saginaw River: Carollton, Saginaw, Buena Vista, Bay City, and Essexville. Prior to 1972, only primary treatment with chlorination was maintained. As of 1972, however, these municipalities agreed to institute secondary treatment with phosphorous removal. During a July 1965 WRC survey, Saginaw City contributed 62.7% of the total 5-day BOD being discharged to the Saginaw River; the Bay City plant contributed another 32.9%. All the plants combined discharged 21,037 lbs/day of BOD to the river. The WRC analyzed composite samples of sewage effluent in the July 1967 survey for a wide variety of parameters (See Figure 8). Monthly

Figure 8 source: Michigan WRC 1971

SAGINAW RIVER

COMPOSITE SEWAGE TREATMENT PLANT EFFLUENT SAMPLES

	Carrollton			Saginaw			Buena Vista			Bay City			Essexville		
	Survey #1	Survey #2	Survey #3	Survey #1	Survey #2	Survey #3	Survey #1	Survey #2	Survey #3	Survey #1	Survey #2	Survey #3	Survey #1	Survey #2	Survey #3
2-day BOD	92			44			88			48			100		
5-day BOD	172	195	70	76	96	56	124	188	123	84	103	91	157	173	130
6-day BOD	180			81			145			105			157		
8-day BOD	204			104			170			130			183		
10-day BOD	225			111			187			141			192		
10-day filtered BOD	130			62			98			68			110		
13-day BOD	250			120			210			157			210		
First stage k_1 rate	0.10			0.085			0.09			0.07			0.11		
Ultimate BOD	255			125			210			175			220		
COD	420	515	397	380	427	155	360	394	305	380		294	380	390	254
Filtered COD	220			120			155			160			160		
pH	6.8			7.2	7.3	7.6	7.2			7.3			7.2		
Suspended solids	130	126	124	122	104	74	122	87	118	118	101	82	108	88	76
Suspended volatile solids	110	104	104	80	53	34	96	60	102	90	75	70	86	61	54
Total solids	1,170			708	812	739	774			1,040			766		
Total volatile solids	344			186			260			260			264		
Phenol				0.06	0.054	0.064	0.05			0.05			0.05		
CN	0.00			0.00			0.00			0.20			0.00		
Cr^6	0.00			0.00			0.00			2.4			0.00		
Cr^3	0.00			0.00			0.00			0.5			0.00		
Fe	1.9			3.0			2.2			1.3			1.0		
Cu	0.0			0.0			0.0			1.0			0.0		
Ni	0.0			0.0			0.0			0.8			0.0		
Zn	0.0			0.0			0.0			0.3			0.0		
NO_2 as NO_2	0.3			0.5	0.15		0.2			0.3			0.2		
NO_3 as NO_3	0.0			0.0			0.0			0.0			0.0		
NH_3 - N	33.0			14			34			13.0			28		
Org. N.	15.0			8			8			12.0			10		
Ortho PO_4	30.0			13			36			13.0			27		
Poly PO_4	10.0			3.5			4.0			4.0			11		
Org. PO_4				6.5						11.0					
Total PO_4				23						28.0					
Anionic Detergent	7.5			4.0			11			4.0			12		
Cl	225			170	243	230	160			335			125		
Chloroform Extractable	46			72			37			42			44		
Aliphatics	3.2			54			4.3			17					
Aromatic	13.4			6			9.0			8					
Oxygenated	23.3			11			18			13					
Flow (M.G.D.)	0.2*	0.2*	0.2*	19.9	21.3	21.3	0.340	0.311	0.327	8.4	9.0	9.4	0.257	0.179	0.318

NOTE: All concentrations except pH and flow are expressed in milligrams per liter. Laboratory determinations for BOD's were made on a dechlorinated and seeded sample.

Survey #1 conducted 0800 on 7/19/65 to 0800 on 7/20/65
Survey #2 conducted 0800 on 7/20/65 to 0800 on 7/21/65
Survey #3 conducted 0800 on 7/21/65 to 0800 on 7/22/65

*Assumed flow

operating reports are also available with limited information for each of the plants. Discharge character has, however, significantly changed since 1972. Information after this date is not presently available.

The major industries that discharge directly to the river include: the Chevrolet-Saginaw Grey Iron Divison of General Motors Corp., the Petrochemical and Bay Refining Divisions of Dow Chemical Company, Michigan Sugar Company, and Monitor Sugar Company. Waste surveys have been conducted on these industries by the WRC on various isolated dates (See Figure 9). Each of the industries has contributed to the high conductivity and total solids content of the Saginaw River.

The two sugar companies operate on a seasonal basis (September to January) and discharge only from October until ice cover and in the spring during high stage. In 1965 they constituted over 99% of the industrial BOD loading to the river and, during discharge time, 35% of the total river BOD loading.

Other miscellaneous sources of waste discharge to the river include commercial shipping, recreational boating, dredging, and storm water overflow from combined sewers which as of 1965 were in all communities except Carollton.

The Michigan WRC as part of their extensive 1965 survey of Saginaw River took numerous D.O. measurements and performed elaborate deoxygenation calculations. They concluded that they were two distinct D.O. sags on the Saginaw River, the most severe occurring below the discharges from the cities of Carollton, Saginaw, and Buena Vista. The other sag occurs below Bay City

Figure 9 [source: Michigan WRC 1971]

SAGINAW RIVER

Chemical Analyses of Composite Samples of Industrial Wastes

	Chevrolet-Saginaw Grey Iron Division of G.M.				Michigan Sugar Company					Monitor Sugar Company			Dow Chemical Company, Petro-Chemical and Bay Refining Division							
	North Outfall		South Outfall		Site #1		Site #2						Bay Refining Crude Unit		Bay Refining Cracking Unit		Petro-Chemical		Raw Water	
	Survey #1	Survey #2	Survey #1	Survey #2	Survey #1	Survey #2	Survey #1	Survey #2	Raw Water	Survey #1	Survey #2	Raw Water	Survey #1	Survey #2	Survey #1	Survey #2	Survey #1	Survey #2	Survey #1	Survey #2
D.O.	---	---	---	---	---	---	---	---	---	---	---	---	---	7.4	---	7.4	---	7.4	---	7.5
1-Day B.O.D.	---	---	---	---	---	---	140	---	---	174	---	---	---	---	---	---	---	---	---	---
2-Day B.O.D.	---	---	---	---	---	---	153	---	---	193	---	---	4.0	---	4.8	---	2.8	---	5.0	---
4-Day B.O.D.	---	---	---	---	---	---	230	---	---	304	---	---	---	---	---	---	---	---	---	---
5-Day B.O.D.	5.0	3.1	2.6	2.6	820	1,100	250	214	4	330	247	9.9	7.2	8.0	8.0	8.0	6.4	7.6	9.0	5.4
7-Day B.O.D.	---	3.8	---	3.2	---	---	270	---	---	335	---	---	10.0	---	10.0	---	6.8	---	10.8	---
9-Day B.O.D.	---	---	---	---	---	---	275	---	---	340	---	---	11.5	---	12.0	---	10.0	---	12.5	---
10-Day B.O.D.	---	5.4	---	4.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
13-Day B.O.D.	---	6.5	---	5.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K_1 Rate	---	0.03	---	0.03	---	---	0.15	---	---	0.22	---	---	0.06	---	0.06	---	---	---	0.06	---
C.O.D.	34	25	21	18	1,400	---	380	---	38	420	---	---	60	71	47	50	51	54	47	47
SO_4	78	80	74	70	---	---	---	---	---	---	---	---	---	87	---	67	---	73	---	67
Org. N	---	---	---	---	---	---	8.0	---	---	9.5	---	---	3.5	---	3.0	---	3.5	---	3.2	---
NO_3-N	3.0	3.0	2.6	2.9	---	---	---	---	---	---	---	---	1.0	1.2	0.9	0.6	0.8	1.2	0.8	0.8
NO_2-N	0.21	0.23	0.17	0.20	---	---	---	---	---	---	---	---	0.26	0.23	0.10	0.10	0.16	0.14	0.13	0.12
NH_3-N	0.0	0.2	0.2	0.2	---	---	6.0	---	0.9	5.0	---	0.4	1.1	0.3	---	0.0	0.4	0.0	0.3	0.4
Org. PO_4	---	---	---	---	---	---	3.0	---	---	3.7	---	---	---	---	---	---	---	---	---	---
PO_4	0.2	0.0	0.0	0.0	---	---	0.0	---	0.5	0.0	---	0.70	1.0	0.7	0.3	0.2	0.6	0.2	0.5	0.6
Fe	0.8	0.8	1.5	2.0	---	---	2.0	---	0.7	2.0	---	0.4	0.7	0.8	0.7	0.9	1.2	0.7	1.0	1.1
Cl	105	260	2[illegible]0	175	---	---	205	---	485	220	---	220	400	400	300	255	285	275	300	275
$CHCl_3$ Ex.	5.2	2.8	2.8	3.6	---	---	---	---	---	---	---	---	2.4	3.6	4.0	1.2	2.8	2.6	1.2	1.6
Anionic Detergent	0.0	0.0	0.0	0.0	---	---	0.1	---	0.2	0.1	---	0.2	0.4	0.4	0.3	0.2	---	0.2	0.2	0.2
CN	0.00	---	0.00	0.00	---	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr^6	0.00	---	0.00	0.00	---	---	---	---	---	---	---	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	0.0	---	0.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ni	0.0	---	0.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pb	0.0	---	0.0	---	---	---	---	---	---	---	---	---	0.00	---	0.00	---	0.00	---	0.00	---
HCO_3	170	175	155	152	---	---	290	---	---	240	---	215	---	170	---	135	---	142	---	142
pH	7.9	8.1	7.6	7.9	6.4	5.7	6.8	7.0	7.7	6.2	6.7	7.7	7.8	7.7	7.7	7.9	7.8	8.0	7.9	7.8
Phenol	0.00	0.00	0.00	0.00	---	---	0.02	---	0.00	0.02	---	0.004	0.008	0.010	0.015	0.015	0.004	0.004	0.004	0.004
Conductivity	950	1,250	1,000	920	---	---	1,200	---	1,820	1,200	---	1,100	---	---	---	---	---	---	---	---
Total Solids	750	904	776	700	---	---	1,036	1,150	---	996	944	---	1,108	1,084	880	746	860	820	903	753
Total Vol. Solids	---	---	---	---	---	---	360	495	---	332	345	---	240	294	208	274	222	256	270	252
Suspended Solids	30	32	20	19	216	156	86	88	28	136	132	17	40	38	30	41	64	53	51	43
Suspended Vol. Solids	14	10	8	6	104	100	78	70	11	70	76	9	16	21	15	20	26	28	19	16
Maximum Flow (gpm)	1,900	1,760	6,960	7,944	664	---	3,008	2,815	---	2,388	2,312	---	---	---	---	---	---	---	---	---
Minimum Flow (gpm)	1,000	1,540	6,535	6,503	182	---	1,100	1,136	---	247	561	---	---	---	---	---	---	---	---	---
Average Flow (gpm)	1,580	1,645	6,754	6,835	339	---	2,016	1,832	---	1,679	1,827	---	---	---	---	---	---	---	---	---
Average Flow (MGD)	2,275	2.365	9.7	9.8	0.488	---	2.9	2.64	---	2.42	2.63	---	3.6	3.5	10.1	10.7	66.3	65.8	80	80
Survey dates																				
From	9/14	9/15	9/13	9/14	10/25	10/26	10/25	10/26	7/20	10/25	10/26	10/26	10/26	10/27	10/26	10/27	10/26	10/27	10/26	10/27
To	9/15	9/16	9/14	9/15	10/26	10/27	10/26	10/27	7/21	10/26	10/27	10/27	10/27	10/28	10/2	10/28	10/27	10/28	10/27	10/28

NOTE: All values except the flow values, pH, and conductivity are expressed as mg/l. Conductivity is expressed as micro-MHOS.

and Essexville. According to the WRC report, at 1965 levels the municipal and industrial discharges from Carollton, Saginaw, and Buena Vista will depress river D.O. to 2.2 mg/l at drought flow of 445 cfs and a temperature of 20° C. The WRC report recommended that loadings be cut to 4000 lbs. of BOD/day in order to maintain a minimum daily D.O. of 4 mg/l. This is 1/5 of the measured loading of July 1965. Similarly, the WRC predicted that the July 1965 discharges from Bay City and Essexville would completely deoxygenate the river in drought conditions (considering no flow reversal). The WRC recommended that loadings be cut by 1/3 (down to 1800 lbs./day) so as to maintain a 4 mg/l D.O. concentration.

Similar calculations were carried out for fall and winter conditions on the river. They predicted a D.O. sag falling to .9 mg/l below Carollton, Saginaw, Buena Vista, and the Michigan Sugar Company, but only a minor sag below Bay City, Essexville, and the Monitor Sugar Company.

Dissolved oxygen measurements from June, July, and October of 1965 demonstrated the predicted sags discussed above. D.O. concentrations rarely went below 4 mg/l; however, these surveys were not taken during a low flow condition.

The D.O. profiles and BOD loadings to the river are expected to have improved since the 1972 implementation of the NPDES system and installation of secondary municipal treatment. Verification of this is not possible for data is not available yet.

The physical and chemical characteristics of the Saginaw River have been documented well since 1963 (EPA, STORET), but the only major sampling station is at the mouth of the river, highly effected by flow reversal from the bay. Temperature, D.O., and BOD data is also available since 1950 at various dates and locations from the Michigan WRC. All data, however, indicates the same conclusion. The Saginaw River water quality is exceptionally poor.

As already mentioned, the BOD and D.O. levels are unsatisfactory. The BOD's in heavy pollutional zones often range as high as 15 mg/l. At the river mouth much of the BOD has already been exerted; yet the BOD's still average between 2 and 6 mg/l. Exceptionally high values have been found in the past below the sugar companies' discharge and during algal blooms. D.O. concentrations vary widely in the river, often falling below the 4 mg/l level, yet equally often demonstrating concentrations greater than 8 mg/l. The D.O. level is heavily dependent on loading, water temperature, location, and flow. Slight improvements in the D.O. concentrations of the river have been noticed in recent years (EPA, STORET). This results from implementation of better treatment facilities within the system and the corresponding decrease in BOD loading. Concentrations of dissolved oxygen still occasionally drop below 4 mg/l, particularly in the summer.

Chloride levels in the river are particularly high. At the river mouth the 10-year average concentration was 163 mg/l. Concentrations often approach 400 mg/l (See Table 2). From recent data, however, it appears that the chloride concentrations may have improved, having decreased by as much as 30% from measurements taken 10 years ago. Other ions such as potassium and sodium were

Table 2: Typical Loadings to Saginaw Bay of Selected Tributaries

	Flow cfs	Phos -D Ortho as P			Total P			NO_3-N			NH_3-N			Org-N			Silica Si			Chlorides		
		range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day	range mg/1	conc mg/1	gm/day
Au Gres	250	.01 to .04	.017	1.04 x 10^4	.02 to .21	.07	4.28 x 10^4	.1 to 1.3	.43	2.63 x 10^5	.02 to .31	.09	5.51 x 10^4	.2 to .9	.56	3.43 x 10^5	1.4 to 5.1	3.5	2.14 x 10^6	11 to 67	33	2.02 x 10^7
Rifle	365	0 to .1	.02	1.78 x 10^4	.02 to .46	.09	8.01 x 10^4	.01 to .35	.15	1.3 x 10^5	0 to .9	.06	5.35 x 10^4	0 to 1.2	.4	3.57 x 10^5	1.4 to 5.6	3.3	2.45 x 10^6	8 to 24	17	1.52 x 10^7
Kawkawlin	162	0 to .2	.064	2.54 x 10^4	.04 to .35	.15	5.95 x 10^4	0 to 11	1.2	4.76 x 10^5	0 to 1.0	.17	6.74 x 10^4	0 to 1.8	.85	3.37 x 10^5	.23 to 4.6	2.2	8.7 x 10^5	9 to 200	67	2.66 x 10^7
Saginaw	3850	0 to 4.6	.16	1.51 x 10^6	.12 to 1.5	.3	2.8 x 10^6	0 to 3.6	1.0	9.42 x 10^6	0 to 2.0	.60	5.6 x 10^4	0 to 1.6	.87	8.2 x 10^6	.46 to 3.5	1.8	1.70 x 10^7	46 to 390	163	1.54 x 10^9

also found in high concentrations. Typical respective concentrations are 6 mg/l and 70 mg/l. Sources of contaminating ions have been attributed to the industrial and municipal discharges within the basin, particularly those of the Tittabawassee River.

Nutrient levels in the river are at elevated concentrations year-round. Inorganic nitrogen levels range often as high as 3 mg/l as N. Nitrate and ammonia levels vary widely but typical levels to be expected would be .5 to 1.5 mg/l NO_3 as N and .2 to 1 mg/l NH_4 as N (See Table 2). Organic nitrogen concentrations average .87 mg/l as N. Phosphorous levels are equally excessive. Dissolved phosphorous concentrations usually range from .1 to .3 mg/l as P with total phosphorous concentrations often double or triple. Nutrients levels do not appear to have improved significantly in recent years. Long-term improvements or degradation cannot be evaluated, since no nutrient data was available prior to 1963.

Biologically the Saginaw River is in a deplorable state. Coliform, plankton, and benthos indicate high degrees of pollution. Unfortunately, as is the case for all the Saginaw River data, biologic information is scarce. The Michigan WRC is responsible for the only significant available study.

In the WRC 1965 study, extremely high total and fecal coliform concentrations were found in much of the river. They occurred at all times of the year, even during periods when contaminant waste waters were chlorinated. The highest concentrations were observed after combined storm water and sanitary discharges to the river. Total coliform concentration generally ranged between 1,000 and 500,000 organisms/100 ml with fecal coliform ranging as high as 60,000 counts/100 mg. Concentrations were highest in the areas surrounding the Carollton, Saginaw, and Buena Vista sewage plant discharges and near the Bay City and Essexville discharges.

During the summer months, phytoplankton in the Saginaw River were extremely productive. They affected the D.O. and BOD of the river significantly. Concentrations in the summer months were 10 times that of the fall, winter, and spring values. Plankton counts well over 25,000 per milliliter were commonly found in the river during the summer months. Concentrations ranged as high as 97,020 per milliliter. Productivity was measured during a two-day period in July 1965 and found to reach levels as high as 2 mg O_2/l/hr. Highest algal activity was found in the vicinities of the city discharges. Most of the algae species found in the survey were considered pollution tolerant, usually found in enriched waters. Large growths of attached filamentous algae were also noted.

Primary production in the summer months appeared to be limited by only the available light energy. The euphotic zone was restricted to only 10% of the waters during the summer months. Light extinction was caused by the algae themselves and other high sources of turbidity. Average secchi disc values were .33 meters. The high light extinction prevented growths of macrophytes on the river bottom despite the bottom's strong organic character and the high nutrient levels present year round.

Sludgeworms and bloodworms, both highly pollution tolerant, composed over 99% of the total benthic population of the Saginaw River sampled in 1965.

Overall the Saginaw River is obviously in an unsatisfactory state, both chemically and biologically. The sources of its contamination include local municipal and industrial discharges as well as its tributary system. Detailed analysis of the conditions and trends in water quality within the river are impossible because of the limited amounts of data available.

The Tributary System of the Saginaw River

a) Shiawassee River

The Shiawassee is 100 miles long and drains an area of 1200 square miles. Fourteen municipal and institutional wastewater treatment facilities and five major industries discharge into the river. Water quality from the mouth of the Shiawassee to Corunna, located about half way upstream, is poor. Excessive mutrient concentrations exist in the entire lower 50% of the river. Within this region, six reaches of substandard water quality have been identified by the WRC (1971) with regard to other water-quality parameters. Three of the six are degraded by inadequately treated sewage (efforts are being made to alleviate this problem). Dissolved oxygen depressions and high coliform densities are also characteristic of these areas. Water quality in the upper portions of the basin is generally improved. However, as a result of municipal discharges, five mainstream reaches and two tributary reaches have substandard quality.

b) Tittabawassee River

The Tittabawassee Basin is approximately 2,620 square miles in area and receives drainage from the Tobacco, Salt, Chippewa, and Pine Rivers. Most of the basin is sparsely populated, although a large industrial center has developed as a result of underground salt deposits. Water quality between Midland and the Saginaw River is very poor. Four reaches of exceptionally substandard water exist in this area according to the WRC (1971). Three are a result of inadequate municipal sewage treatment and exhibit high coliform and nutrient levels and depressed dissolved oxygen content. The most severe drop in water quality occurs below Midland where the river receives discharges from the municipal wastewater treatment plant and the Dow Chemical Company. The river also experiences increased heat content; lowered D.O.; and elevated levels of suspended and dissolved solids, conductivity, temperature, pH; and taste and odor producing substances. On isolated occasions excessive amounts of toxic materials have occurred due to lapse in treatment operations. High fish mortalities were also noted.

The principal water-quality problem of the Tittabawassee is the high dissolved solids content, particularly chlorides. The Tittabawassee constitutes the major source of chlorides within the entire Michigan basin to Lake Huron. It is the major chloride polluter of the Saginaw River and Bay.

The Pine River tributary, below the Alma-St. Louis area, is substandard in quality (WRC, 1971). It receives discharges from two municipal treatment plants and local petroleum and chemical industries. Chlorides increase fourteenfold below this area with lesser increases of nutrients, toxics, and suspended solids. Dissolved oxygen levels and oil discharges also result in substandard quality.

The Chippewa River has one reach of substandard quality, receiving wastes from a municipal treatment plant and an industrial discharge.

c) The Flint River

The Flint River Basin has a drainage area of 1,350 square miles and receives tributary water from North Branch, South Branch, Farmers Creek, and Mistequay Creek. There are seven municipal and institutional wastewater discharges to the river, plus nine major industrial dischargers. The most serious breach in water quality occurs below the City of Flint according to the Michigan WRC. The Flint wastewater treatment plant contributes heavily to the river's high organic content and high nutrient levels. The result is depressed D.O. concentrations and excessive algae and aquatic weed growths. Above the treatment plant the river is degraded by storm water overflows, tributary waste loads, and poorly treated sewage discharges. Upstream from Flint the water quality is generally good except for one lapse in which a municipal discharge is located. Efforts are being made to improve the discharge characteristics of most municipal and industrial wastewater discharges. Although the Flint River accounts for only 25%

of the Saginaw River flow, it contributes over 40% of the annual phorphorous loading.

d) The Cass River

The Cass River basin encompasses 931 square miles in six counties. It receives discharge from six municipal treatment plants and several industries, including a sugar company and a milk processing company. Upstream reaches of the river exhibit good D.O. and BOD characteristics. The D.O. levels are depressed and BOD levels elevated, however, below population and industrial centers. The problem is severe during the summer periods of low flow and high temperatures. As a result of these centers, nutrient enrichment is high in the lower stream. Total and fecal coliforms are also at very high concentrations.

Au Gres River

The Au Gres River has a drainage area of approximately 420 square miles and a gross estimated average flow of 250 cfs. One municipal lagoon and one industry discharge into this river. Water quality is generally good throughout the river except for localized bacteriological problems. One reach of the Au Gres' high water quality is breached by the sewage discharges. High coliform and nutrient levels are present there. Chloride levels average about 25-35 mg/l as N of organic ntirogen; .02 mg/l as P of dissolved P; and .07 mg/l as P of total phosphorous (see Table 2).

Rifle River

The Rifle River drains an area of 387 square miles and has a gross average flow of approximately 350 cfs. It receives discharges from one industry and one municipal plant. Water quality is generally very good throughout the basin. Chloride and nutrient concentrations are generally very low. A slight seasonal increase in nitrogen levels (from December to March) has been noted at the river mouth. Good D.O. and BOD characteristics are exhibited throughout the river. Only one localized reach of substandard water quality exists (WRC, 1971). This occurs below the two discharges. Slight D.O. depressions and high nutrient and coliform concentrations are noted there at times.

Representative nutrient concentrations at the mouth are .02 mg/l as P of dissolved phosphorous; .09 mg/l as P of total phosphorous; .15 mg/l as N of nitrate; .06 mg/l as N of ammonia; and .4 mg/l as N of organic nitrogen. Chloride concentrations averaged 17 mg/l (EPA, STORET).

Tawas River

The Tawas River has a small drainage basin of approximately 115 square miles. It receives discharges from one municipal treatment plant. Water quality is generally good with the exception of two localized areas. One is, as expected, near the municipal discharge. The other occurs at the mouth of the river where high coliform densities are found from yet unidentified origin. In general, the D.O. and BOD characteristics are good and nutrient concentrations fair.

Representative nutrient concentrations at the mouth might be .2 mg/l as P of phosphorous, .2 mg/l as N of nitrate, and .3 mg/l as N of ammonia. Chloride concentrations average 10 mg/l.

Pine River

The Pine River collects drainage from the North, Middle, and South Branch Rivers as well as other minor tributaries, combining to a total drainage area of 99 square miles. Only one municipal wastewater treatment plant discharges into this river. Water quality in the Pine River is fair. Dissolved oxygen concentrations are high but BOD loadings indicate moderate organic loading to the stream. Elevated chloride concentrations have been reported. A typical chloride level might be 60-100 mg/l. The waters are also considered to have nutrient enrichment. Total phosphorous concentrations often average over .4 mg/l as P. Nitrogen levels generally are around 2 mg/l as N, and nutrient concentrations appear to have improved in recent years. Total and fecal coliform densities in the river are moderate to high.

Kawkawlin River

The Kawkawlin River basin drains approximately 224 square miles of land and receives a discharge from one municipal treatment plant. Coliform concentrations are low upstream but increase near the river mouth. BOD levels indicate organic enrichment throughout the river; however, D.O. levels are generally good. Chloride concentrations are moderate but sometimes problematic. Nutrient levels are not troublesome. Flow reversal is similar to that observed in the Saginaw River

Typical concentrations at the river mouth are .06 mg/l dissolved phosphorous as P, .1 mg/l total phosphorous as P, 1.2 mg/l nitrate as N, .17 mg/l ammonia as N, .9 mg/l organic nitrogen as N and 70 mg/l of chlorides (see Table 2).

Sebewaing River

The Sebewaing River has a drainage basin of 110 square miles. Water quality is generally good in its upper stretches but poor in its lower reaches. BOD and D.O. concentrations indicate clean water conditions upstream but organic enrichment and D.O. depression exist at the river mouth. High total and fecal coliform densities are noted throughout the river. Nutrient concentrations increase downstream but are not considered excessive. Chlorides are moderately high in the lower river, especially from August to September.

Typical concentrations at the river mouth are: .2 mg/l total phosphorous as P, 2 mg/l NO_3, .3 mg/l ammonia as N, 1 mg/l organic nitrogen as N, and 60 mg/l chlorides.

Other Contaminant Sources

Besides the tributary sources already mentioned, there exist several other minor tributaries on which little or no data is available. These include Silver Creek, Saganing River, Pinconning River, Quinacassee River, Squaw Creek, Wiscoggin Drain, Pigeon River, and Pinnebog River. Their total output is considered to be very inconsequential.

There are no direct municipal discharges to the Saginaw Bay and only a few industrial discharges. These include power plant cooling waters near the Saginaw River and at Quinacassee, and dairy and sugar companies near Sebewaing. All exert definite localized effects on the bay.

V. Physical and Chemical Considerations

The physical and chemical parameters that have been measured in Saginaw Bay are dealt with individually in Section V. First, a short general description of the parameter and its importance is presented followed by a description of the existing and historical conditions of the parameter in the bay. Spatial and temporal trends have been noted when observable and available, and are presented on figures 10-18 and Tables 3 and 4. It should be noted here, first, however, that all trends and conclusions drawn are subject to error as a result of the limited amounts of sampling data.

The majority of the conclusions drawn in the following section were derived from the six principal sources of data listed below.

1. Beeton, A. M.; Smith, S. H.; and Hooper, F. H. "Physical Limnology of Saginaw Bay," Great Lakes Fisheries Commission Tech. Rep. #12, 1967. A 1956 study of over 50 stations in Saginaw Bay from June-October. This is the only good, comprehensive study. It included measurements of temperature, dissolved oxygen, calcium, magnesium, potassium, sodium, phosphorous, sulfate, alkalinity, specific conductance, and wind conditions. The survey did not measure any forms of nitrogen, differentiate the forms of phorphorous, or make sufficient subsurface measurements.

2. Michigan Stream Control Commission, "Saginaw Valley Report," May 1937. A 1935-36 survey of the bay which included measurements of hardness, alkalinity, turbidity, and chloride. The chloride information was only from

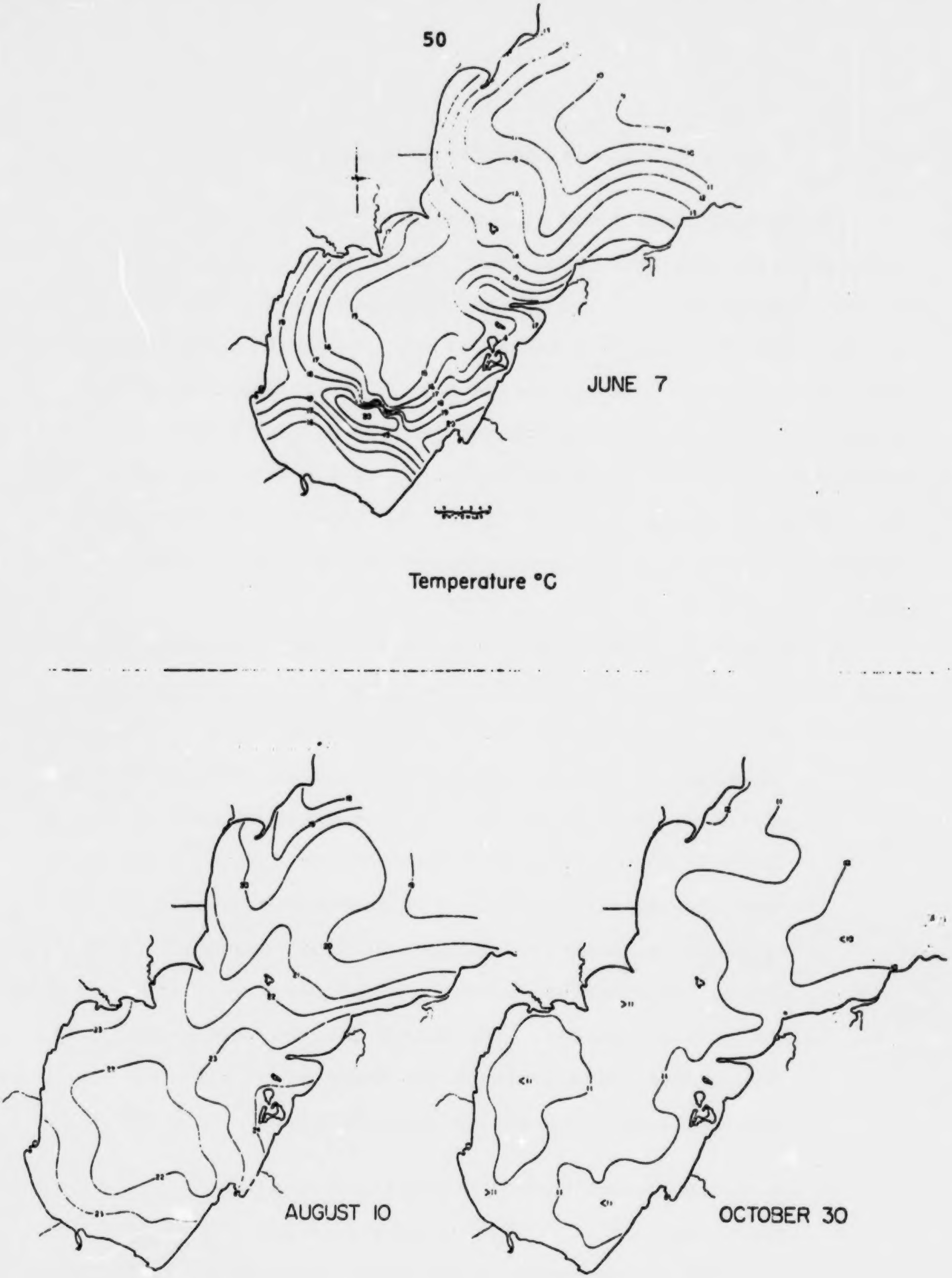
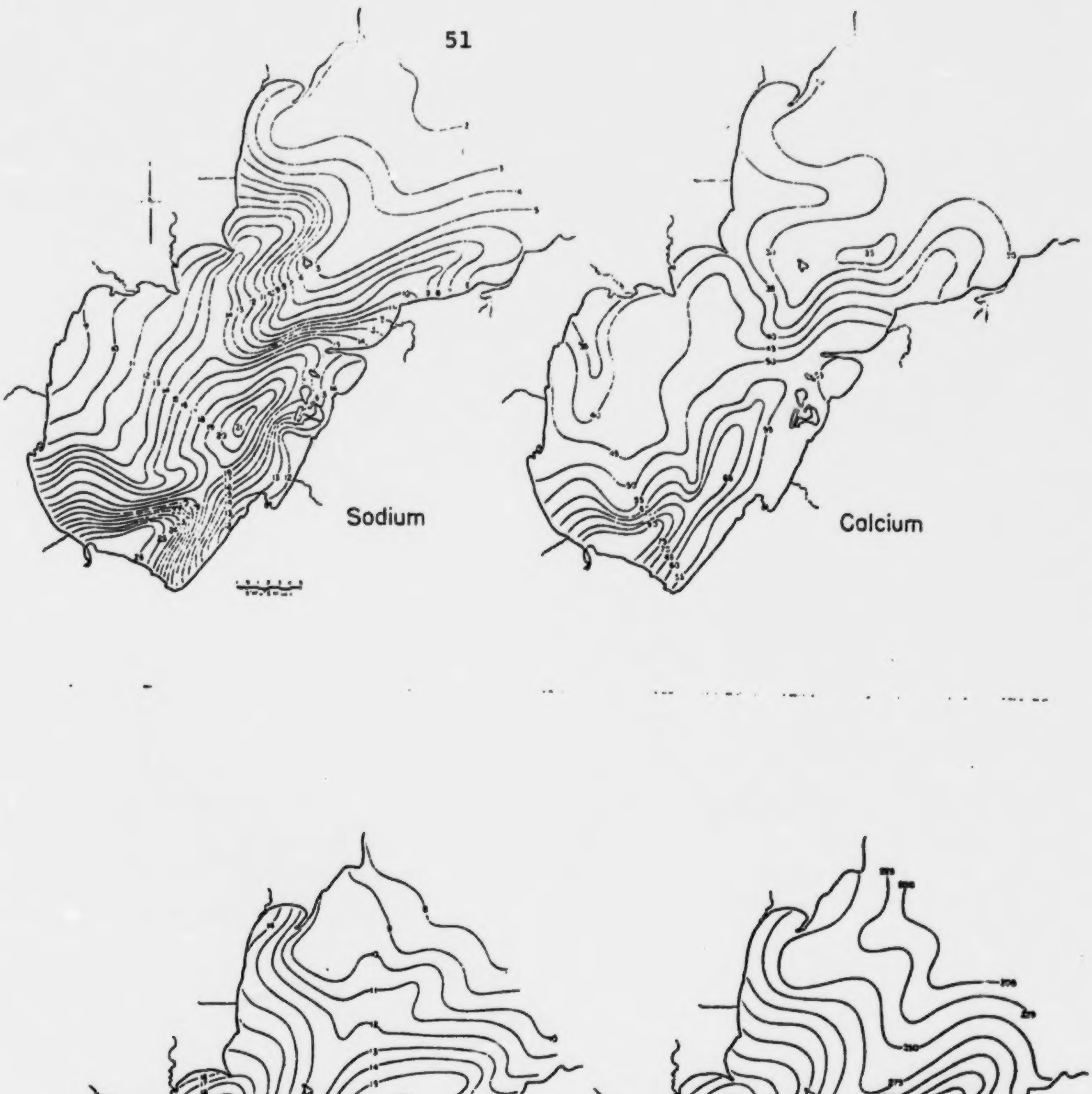


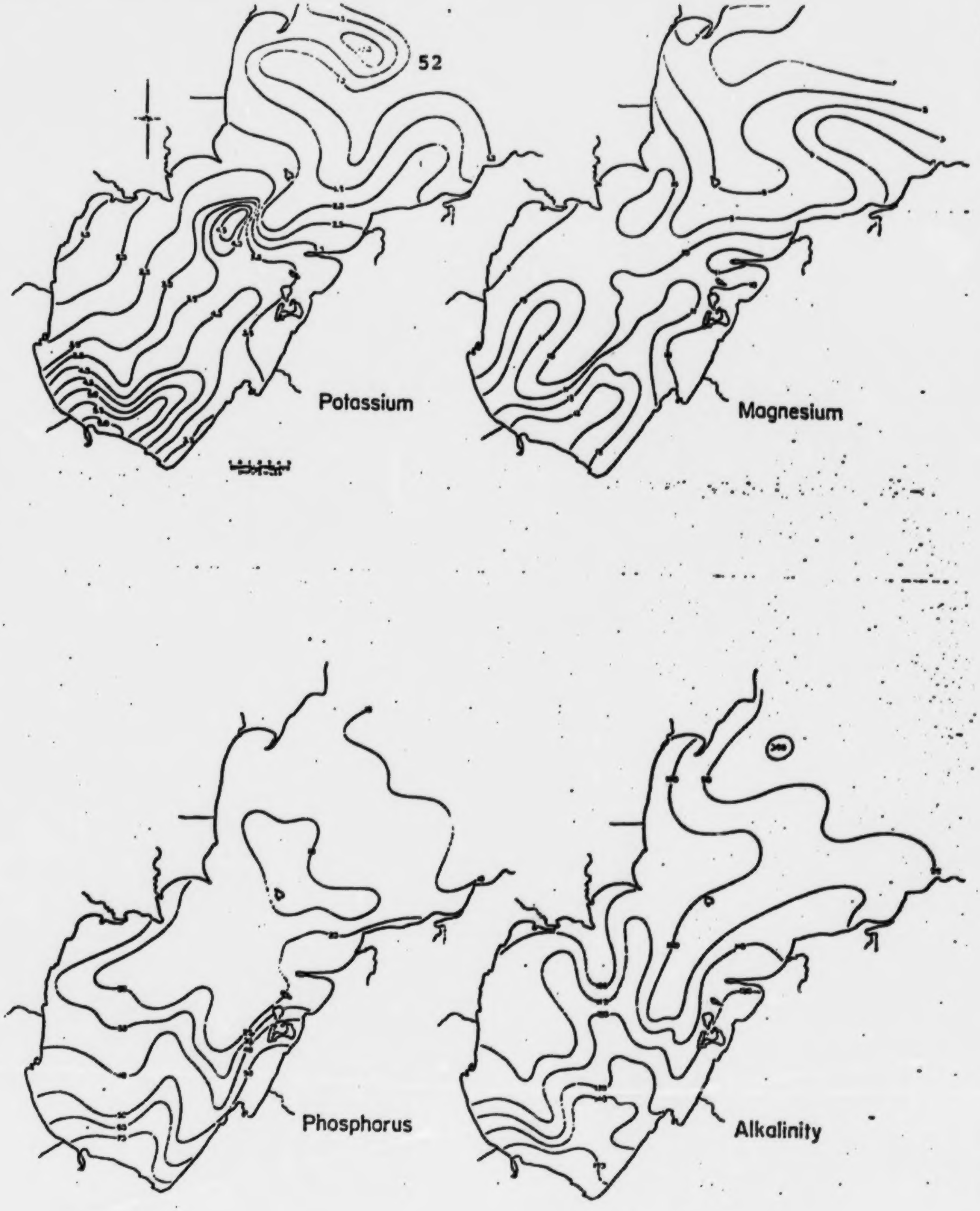
Figure 10. Surface temperatures (°C) of Saginaw Bay during synoptic cruises on June 7, August 10, and October 30, 1956.

Source: Beeton, et al., 1967.



Distribution of sodium, calcium and sulfate (ppm), and conductivity (µmhos at 18 °C) in Saginaw Bay, June 7, 1956.

Figure 11   source: Beeton et al., 1967



Potassium

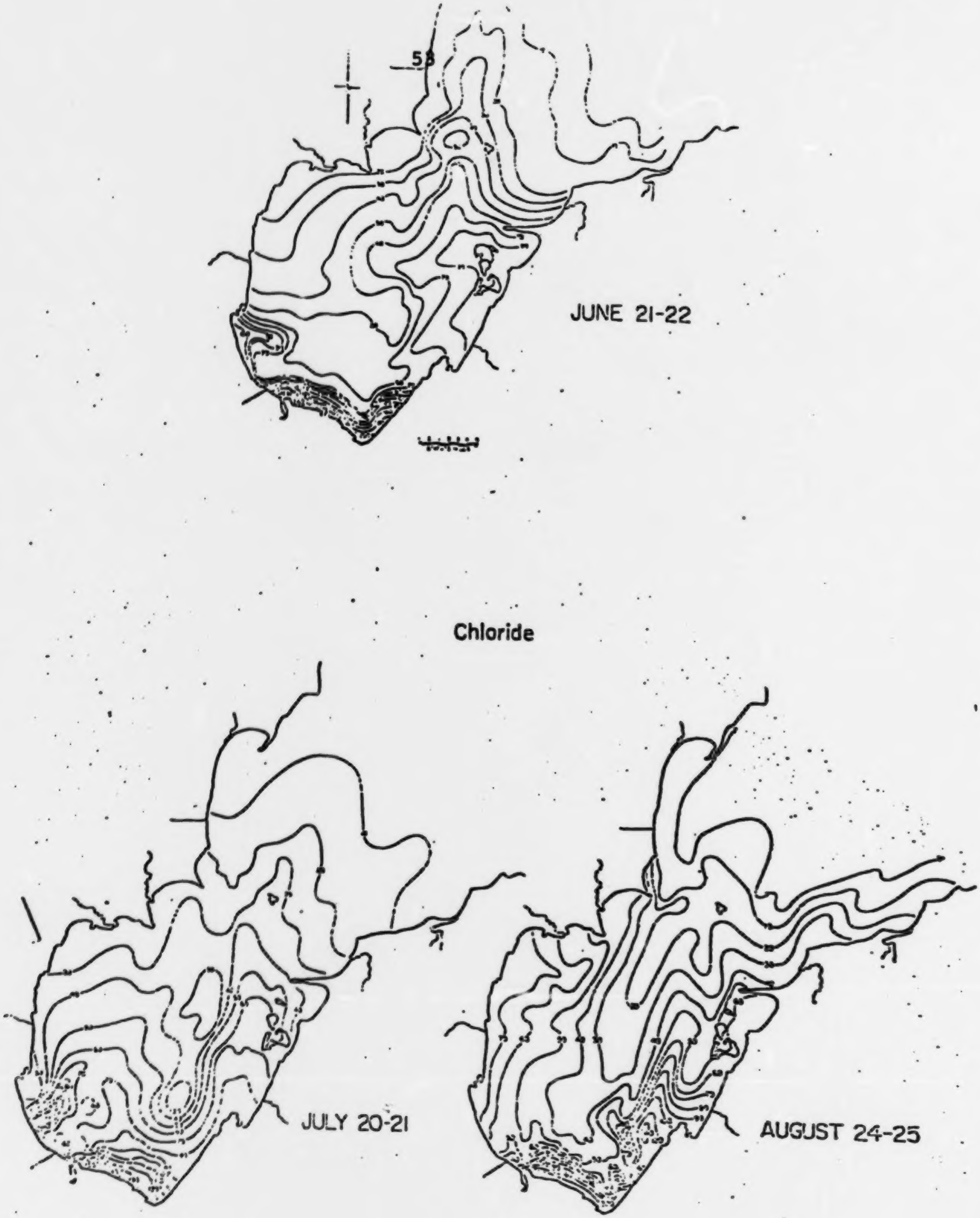
Magnesium

Phosphorus

Alkalinity

Distribution of potassium and magnesium (ppm), phosphorus (ppb), and alkalinity (ppm $CaCO_3$) in Saginaw Bay, June 7, 1956.

Figure 12 source: Beeton et al., 1967



Distribution of chloride (ppm) June 21-22, July 20-21, and August 24-25.

Figure 13 source: Beeton et al., 1967

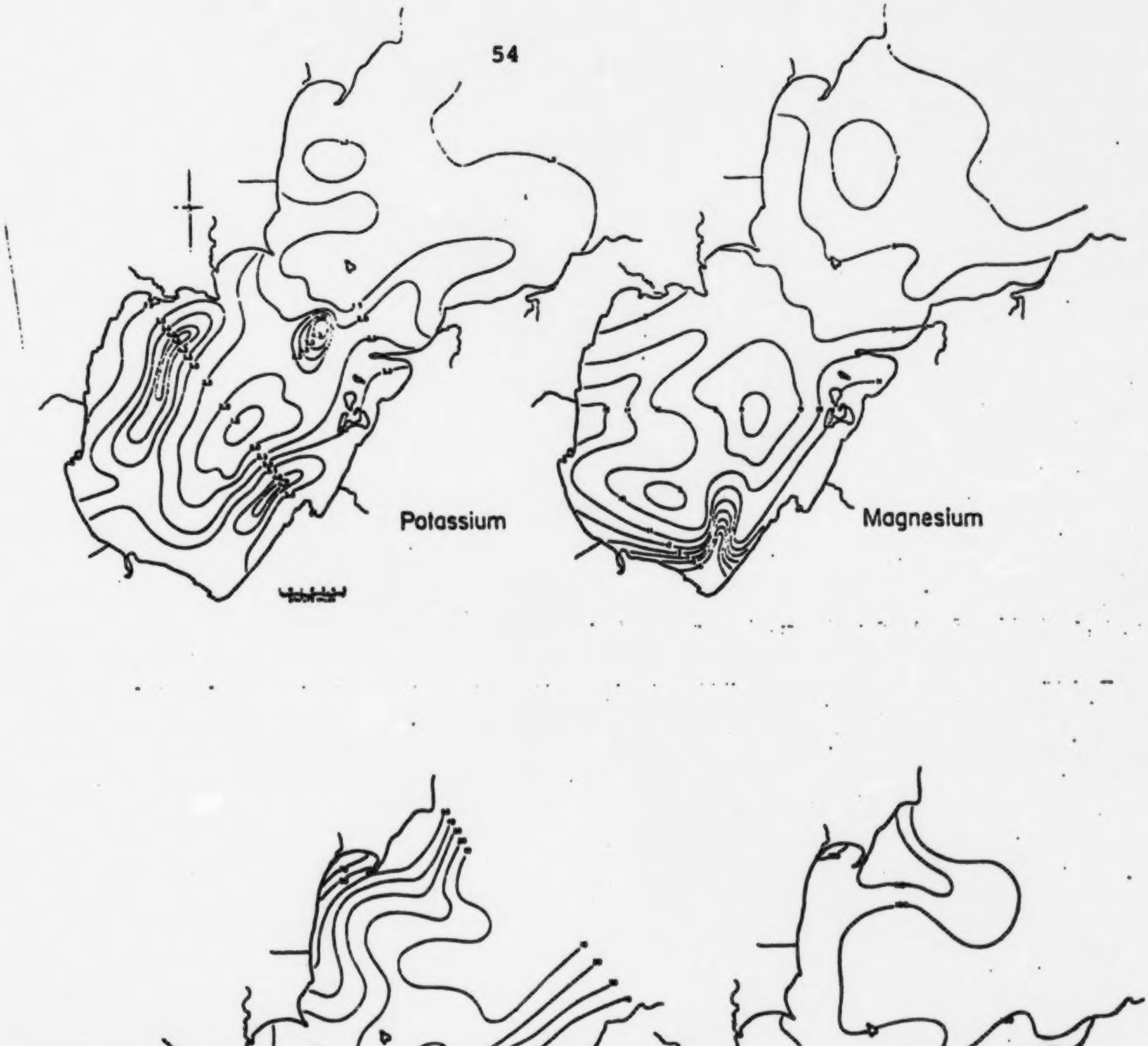
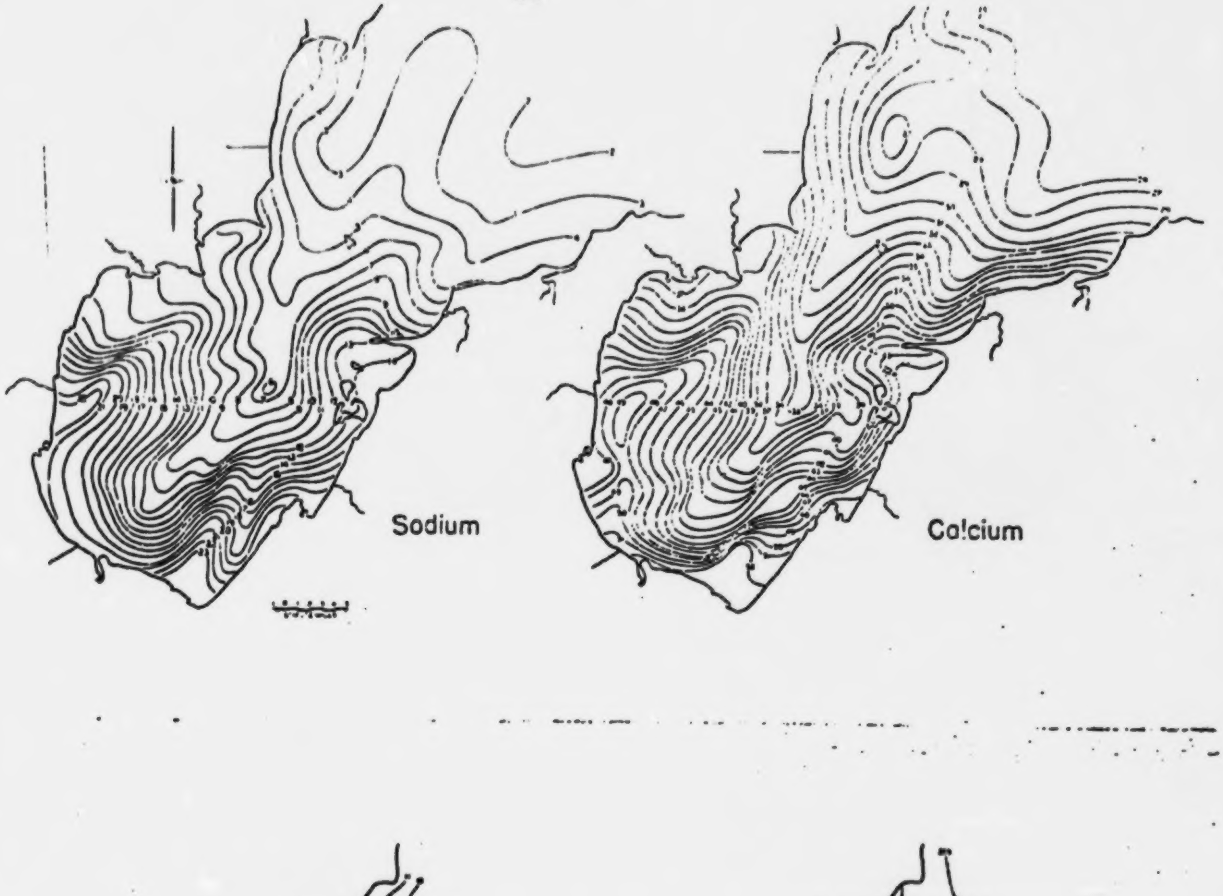


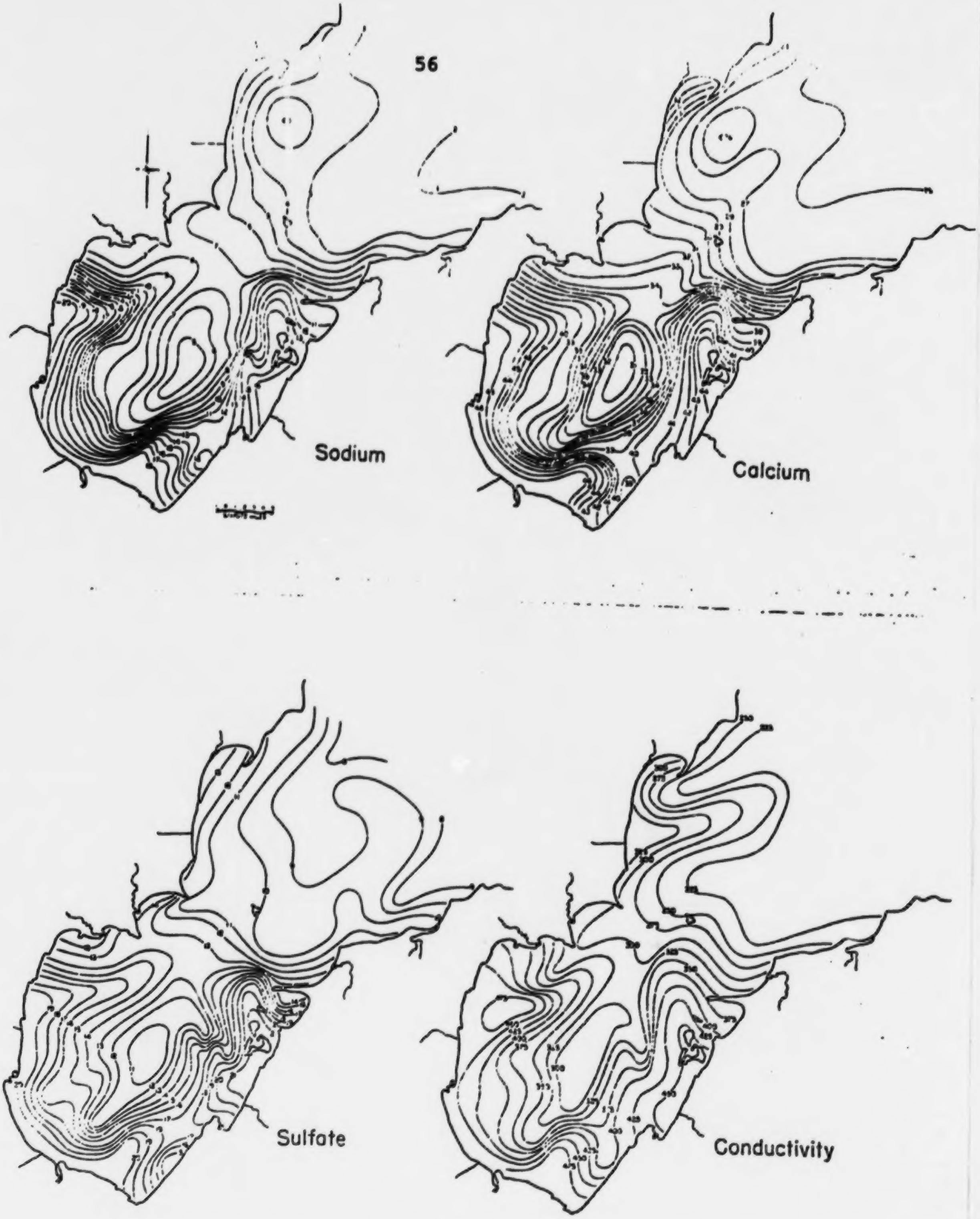
Figure 14 Distribution of potassium and magnesium (ppm), phosphorus (ppb), and alkalinity (ppm $CaCO_3$) in Saginaw Bay, August 10, 1956.

source: Beeton et al. 1967



Distribution of sodium, calcium and sulfate (ppm), and conductivity (µmhos at 18°C) in Saginaw Bay, August 10, 1956.

Figure 15 source Beeton **et** al., 1967



Sodium

Calcium

Sulfate

Conductivity

Distribution of sodium, calcium and sulfate (ppm), and conductivity (μmhos at 18° C) in Saginaw Bay, October 30, 1956.

Figure 16 source: Beeton et al., 1967

MEAN SURFACE D.O. SATURATION
SAGINAW BAY

July and August 1966

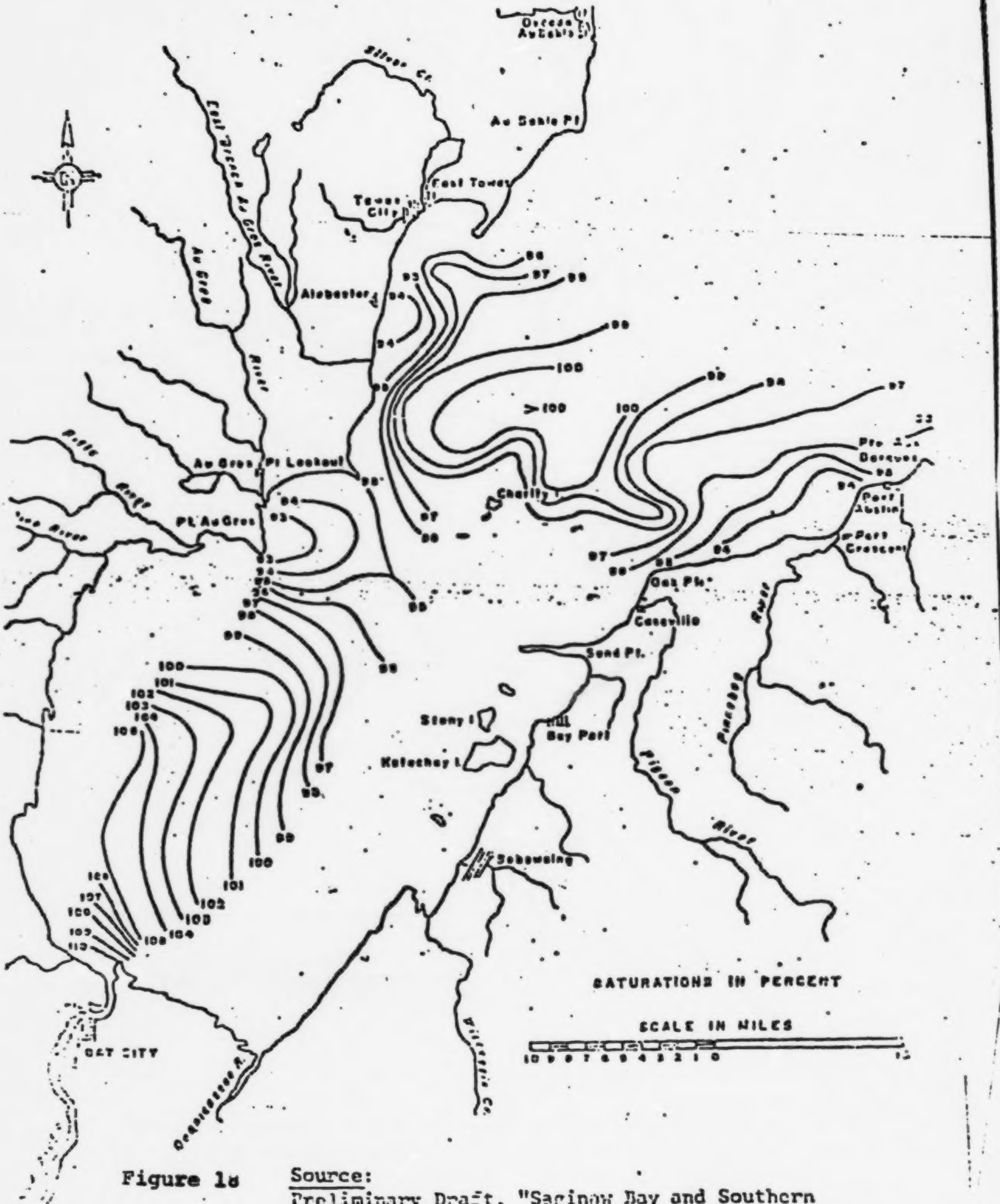


Figure 18

Source:
Preliminary Draft, "Saginaw Bay and Southern Lake Huron Tributaries - Michigan, Water Quality Data, 1965 Survey." FWPCA. January 1969.

Mean Bottom D.O. saturation levels
July and August 1966

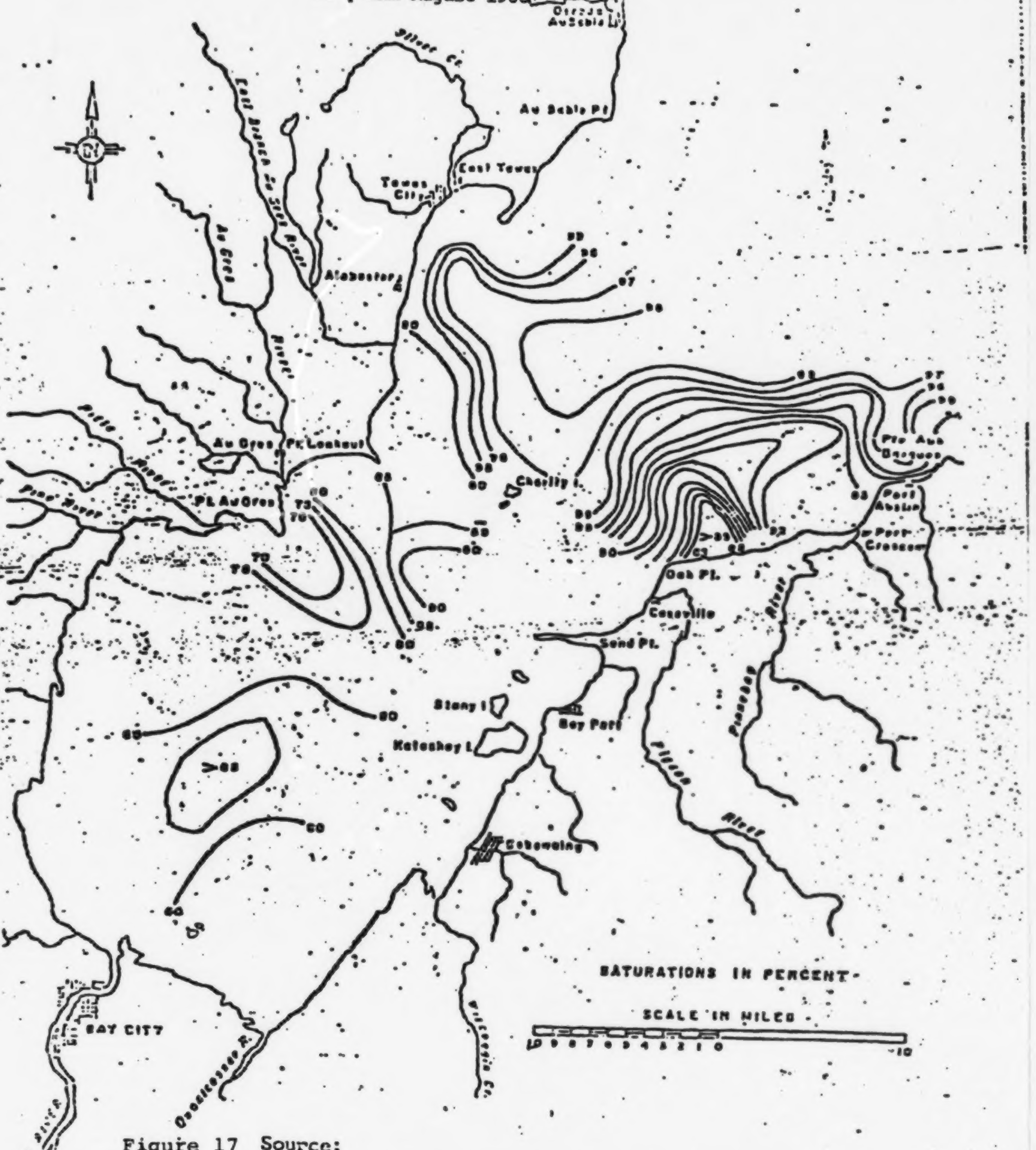


Figure 17 Source:
Preliminary Draft, "Saginaw Bay and Southern Lake Huron Tributaries - Michigan, Water Quality Data, 1965 Survey." FWPCA. January 1969

Average chemical characteristics of water samples taken in the inner area (inside line A-B, Fig. 1), of Saginaw Bay in 1956

Date	Cations					Anions				Specific conducta (µmhos 1
	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total cations (epm)	Bicarbonate[1] (ppm)	Chloride (ppm)	Phosphorus (ppm)	Sulfate (ppm)	
June 7	55	11.2	3.6	15.8	4.44	155	-	0.045	29	553
June 22	-	-	-	-	-	-	57.5	-	-	-
Aug. 10	45	10.6	3.0	16.2	3.90	139	-	0.037	22	463
Aug. 25	-	-	-	-	-	-	61.4	-	-	-
Oct. 30	39	9.4	2.0	11.6	3.27	135	-	0.042	16	391
Average	46	10.4	2.9	14.5	3.87	143	59.5	0.041	22	469
Average expressed as epm	2.31	0.86	0.07	0.63	3.87	2.34	1.68	-	0.46	-
World average freshwater as epm[2]	1.49	0.42	0.08	0.36	2.35	1.71	0.23	-	0.37	-

[1] Determined from total alkalinity measurements.
[2] Gorham, 1957.

Average chemical characteristics of water samples taken in the outer area (between lines A-B and E-F, Fig. 1), of Saginaw Bay in 1956

Date	Cations					Anions				Specifi conducta (µmhos 18
	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)	Total cations (epm)	Bicarbonate[1] (ppm)	Chloride (ppm)	Phosphorus (ppm)	Sulfate (ppm)	
June 7	31	8.1	1.5	4.3	2.44	117	-	0.013	12	270
June 22	-	-	-	-	-	-	13.6	-	-	-
Aug. 10	29	7.5	1.2	3.6	2.25	123	-	0.024	12	253
Aug. 25	-	-	-	-	-	-	8.4	-	-	-
Oct. 30	27	7.9	1.0	2.9	2.15	113	-	0.016	10	237
Average	29	7.8	1.2	3.6	2.28	118	11.0	0.018	11	253
Average expressed as epm	1.45	0.64	0.03	0.16	2.28	1.93	0.31	-	0.23	-
World average freshwater as epm[2]	1.49	0.42	0.08	0.36	2.35	1.71	0.23	-	0.37	-

Table 3 source : Beeton etal., 1967

[1] Determined from total alkalinity measurements.
[2] Gorham, 1957.

Table 4 source: GLRD Univ. of Michigan 1973

TABLE 12. Lake Huron dissolved oxygen, silica, nitrate nitrogen, ammonia nitrogen, soluble reactive phosphate and particulate phosphate. Data for each parameter are given as the mean ± one standard deviation followed by the number of observations in parenthesis.

Depths	Dissolved oxygen, ppm	SiO_2, ppm	NO_3-N, ppb	NH_3-N, ppb	Sol. PO_4, ppb	Part. PO_4, ppb
Zone I						
All	10.7 ± 0.79 (23)	1.29 ± 0.33 (21)	145 ± 30 (21)	12.6 ± 3.0 (20)	2.7 ± 3.2 (8)	23 ± 12 (6)
Surface	10.1 ± 0.37 (6)	1.07 ± 0.15 (7)	139 ± 31 (7)	13.6 ± 5.7 (7)	2.5 ± 1.7 (3)	13 ± 0.78 (2)
3 m	10.2 ± 0.49 (4)	0.94 (1)	111 (1)	10.0 (1)	1.5 (1)	28 (1)
8-22 m	11.0 ± 0.67 (8)	1.20 ± 0.13 (8)	147 ± 26 (8)	11.0 ± 2.6 (7)	3.8 ± 5.4 (3)	21 + 12 (2)
32-30 m	11.5 ± 0.67 (5)	1.80 ± 0.16 (5)	159 ± 33 (5)	13.8 ± 2.5 (5)	1.0 (1)	41 (1)
Zone II						
All	10.6 ±1.0 (24)	1.15 ± 0.42 (23)	150 ± 35 (23)	25.7 ± 9.5 (20)	2.7 ± 1.4 (16)	22 ± 26 (22)
Surface	9.51 ±0.27 (8)	0.81 ± 0.15 (8)	141 ± 24 (8)	20.0 ± 6.2 (6)	2.4 ± 0.78 (8)	19 ± 23 (7)
3 m	9.90 (1)	0.73 (1)	146 (1)	15.0 (1)	-----	17 (1)
8-22 m	10.8 ±0.73 (10)	1.15 ± 0.23 (9)	159 ± 24 (9)	28 ±11 (9)	2.7 ± 2.3 (3)	33 ± 22 (10)
32-80 m	11.8 ±0.20 (5)	1.78 ± 0.19 (5)	190 ± 52 (5)	31.8 ± 5.3 (4)	3.2 ± 1.6 (5)	11 ± 14 (4)
Zone III				Saginaw Bay		
All	9.53 ± 0.48 (18)	1.00 ± 0.22 (18)	42 ± 38 (18)	25.0 ± 9.2 (16)	6.3 ± 6.5 (12)	34 ± 14 (15)
Surface	9.58 ± 0.50 (6)	1.08 ± 0.26 (6)	21 ± 16 (6)	20.0 ± 3.7 (5)	6.6 ± 6.9 (6)	37 ± 19 (6)
3 m	9.67 ± 0.50 (6)	1.03 ± 0.22 (6)	32 ± 26 (6)	23.4 ± 4.7 (5)	-----	33 ± 11 (3)
8-22 m	9.35 ± 0.48 (6)	1.06 ± 0.23 (6)	72 ± 48 (6)	33 ±11 (6)	4.0 ± 3.8 (6)	30 ± 11 (6)
32-80 m	-----	-----	-----	-----	-----	-----
Zone IV						
All	9.81 ± 0.38 (15)	0.86 ± 0.21 (16)	146 ± 27 (16)	21.4 ±7.6 (12)	3.3 ± 1.3 (2)	12 ± 7.6 (13)
Surface	9.40 ± 0.20 (5)	0.65 ± 0.11 (5)	136 ± 85 (5)	21.3 ±9.9 (4)	4.2 (1)	12 ± 5.4 (5)
3 m	-----	0.73 (1)	123 (1)	22.0 (1)	-----	-----
8-22 m	10.0 ± 0.26 (10)	0.98 ± 0.17 (10)	154 ± 23 (10)	21.4 ±7.4 (7)	2.4 (1)	12 ± 9.0 (8)
32-80 m	-----	-----	-----	-----	-----	-----

surface samples but otherwise was complete spatially. All other measurements came primarily from shore area stations.

3. Raw data from a 1966 survey by the U.S. Lake Survey Center. Included only 4 stations, all in the outer reaches of the bay.

4. Schelske, C.L. and Roth, J.C. "Limnological survey of Lake Huron," GLRD University of Michigan, 1973, Pub #17. Data from a July 1970 survey on Lake Huron that included 6 stations in Saginaw Bay. Only average values were available for parameters measured on this survey.

5. Limited amounts of data from cruises carried out by the Canadian Center for Inland Waters.

6. Raw information from the Michigan Water Quality Municipal Water Intake data: "Water Resource Uses," Michigan WRC, 1967.

Alkalinity

General Considerations

Alkalinity is not a specific substance but rather a measure of a waters ability to neutralize acids and is expressed in terms of an equivalent amount of calcium carbonate. It results from the combined effects of several substances and conditions. In natural waters it is due primarily to the salts of weak acids, although weak and strong bases may also contribute. Bicarbonates, carbonates, and hydroxides constitute the major sources of alkalinity since they leach heavily into waters through the action of carbon dioxide on soils and rocks. Borates, silicates, phosphates, and organic substances also contribute, but to a lesser extent.

Alkalinity is also an indirect measure of a water's buffer capacity, its ability to resist change in pH due to the addition of acids or bases. This buffering ability is important to prevent changes in pH that might prove harmful to biotic communities. Most organisms are acclimated to a specific pH range and, if exposed to conditions outside of this range, they can experience deleterious effects. Diurnal photosynthetic activity can cause fluctuations in pH. These changes are controlled by the alkalinity and, hence, are usually small enough and temporary so as not to cause harm.

In general it can be stated that alkalinity has not been shown as yet to be lethal to fish if the pH is kept below 9. Other effects on fish have only been noted at low alkalinity and pH conditions. Carbonate alkalinity seems to have no harmful effect on plankton or other aquatic life. It has been theorized that high alkalinity is antagonistic towards toxicity of copper sulfate to fish.

Observed Conditions

The alkalinities measuring in the bay by Beeton et al. (1967), during surveys from June 7 to October 30, 1966 show values ranging from approximately 90 to 150 ppm as $CaCO_3$ (see figures 12 and 14). These alkalinities offer a sufficient buffer capacity to support a diverse aquatic community, given other favorable conditions. Spatially, the alkalinities tend to have higher values at the south and southeastern portions of the bay, with maximal values occurring at the mouth of the Saginaw River. Lowest alkalinities were observed near the mouth of the bay. The distribution is a result of inflow from the Saginaw River, where concentrations range from 123 to 187 ppm (as measured by the Dow Chemical Company in spring and summer of 1956). These high alkalinity waters increase the natural background alkalinity of the Lake Huron waters (below 90 ppm according to the U.S. Lake Survey Center's Lake Huron Limnological Data). The higher alkalinities tend to follow the northeasterly flow of the Saginaw River water within the bay. This trend does not always, however, extend pronouncedly very far beyond the mouth of the river due to the variable circulation in the bay. Distribution is regulated thereafter by the diluting effect of the Lake Huron waters. In general, alkalinity concentrations averaged between 110 and 125 ppm in the inner bay and approximately 100 ppm in the outer bay. The values in the outer bay are confirmed by data from the U.S. Lake Survey and Canadian Center for Inland Waters.

Temporally it appears that the alkalinity has increased slightly in the last 30 years. According to the Saginaw Valley Report of 1937 (Michigan Stream Control Commission), values for alkalinity at 11 stations along the coastal regions of the bay (excluding the most southerly end) varied from 82 to 124 ppm with the average value in the low 90's. The alkalinities at the mouth of the Saginaw River ranged from 95 to 185 ppm. Although this data is lacking in both station location and numbers, it does seem to indicate that the alkalinities may have increased as much as 10 to 15 ppm in the last 30 years.

The Stream Control Commission's data also reflects the diluting effect of the Lake Huron waters although any further circulation pattern from the alkalinities cannot be ascertained because of the location of the sampling stations (now relocated within the central portions of the bay) and their scarcity.

Locally within the bay there appears to be no severe vertical distribution of alkalinity. The Lake Survey data, however, indicates alkalinities of 1 to 3 ppm higher in the hypolimneon during summer stratification. This may be coincidental, a methodological error, or it may have a limnological basis. It is possible that the photosynthetic activity in the epilimneon produces $CaCO_3$ precipitation through uptake of CO_2 and a shift in carbonate equilibrium. The precipitated $CaCO_3$ settles into the hypolimneon where it meets aggressive CO_2 concentrations as a result of bacterial decomposition. The end result is resoluablization of the $CaCO_3$ and an increase in alkalinity. Although this phenomenon can occur, the Saginaw Bay data is insufficient to positively document it.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand is usually defined as the amount of oxygen required by bacteria to stabilize or oxidize decomposable organic matter under aerobic conditions. High BOD's are undesirable because of their resulting oxygen depletion and their deleterious effect on fish and other aquatic life. A water's ability to satisfy a BOD without harmful effects is dependent on the BOD and oxygen levels, mixing characteristics, surface to volume ratio, temperature, photoproductivity, as well as many other parameters.

Unfortunately no significant BOD data was found concerning the Saginaw Bay. The effects of its exertion will, however, be discussed in the section dealing with dissolved oxygen.

Calcium

General Considerations

The ions of calcium salts are among the most common constituents found in natural waters. Calcium is the principal cation imparting hardness into most surface waters, often to the degree that they are inadequate for municipal or industrial use. Sources of calcium include natural leaching from soils and rocks and discharges from municipal and industrial wastes.

Calcium has not been shown to be harmful to aquatic life at reasonable levels. Fish have survived in synthetic concentrations of Ca over 2500 ppm. Calcium has further shown to be antagonistic towards the toxicity of lead and zinc.

No U.S. Public Health drinking water standards or Michigan water quality standards have been set regarding calcium, although the World Health Organization (WHO) recommends 75 mg/l as a limit and

200 mg/l as an acceptable limit for drinking water.

Observed conditions

In the 1956 survey (Beeton et al., 1967) calcium values were found to range from 25 to 80 ppm (see figures 11, 15, and 16). On the June 7 survey, concentrations were found to be heaviest along the south and southeastern portions of the bay. Nearing the outer bay, concentrations approached the normal Lake Huron background values of 20 ppm. This again indicates the influence of the high solids content of the Saginaw River and diluting waters of Lake Huron. The October 30 survey demonstrated high concentrations (40-50 ppm) at the mouth of the Saginaw River decreasing to lesser values in the outer bay (20-30 ppm). A distinctive counterclockwise circulation of Saginaw River waters was not noted as before due to a probable difference in wind conditions. Overall concentrations appeared to be greatest in the June survey (max 80 ppm) and least in the October survey (max 46 ppm). This may be a result of differences in river flow, higher in the spring and lower in the fall but may also be coincidental.

The Lake Survey data for the outerbay agrees with the 1956 survey showing chloride values from 15 to 32 ppm. The Michigan Stream Control Commission study of 1936 did not include calcium sampling. It did include hardness, data which is closely related to calcium. It indicated a pollutional source from Saginaw River with a diluting effect from the Lake Huron waters. Hardness concentrations ranged from 358 ppm as $CaCO_3$ right at the Saginaw

River mouth to 85 ppm in the outerbay.

In general, the calcium and hardness levels in the bay are excessive but not troublesome. They may at times violate WHO drinking water recommendations (75 mg/l Ca) but always fall below the acceptable limit. Bay water may need to be softened for specific industrial and municipal uses.

Chlorides

General Considerations

The chloride ion is a common constituent of most natural waters and has high solubility characteristics. The chloride ion is involved in very few natural removal reactions. It is, therefore, considered to be a conservative ion and is often used as tracer in pollutional and flow studies. Sources for chlorides include mineral solution, agricultural runoff, ground water, and industrial and municipal discharges. Chloride levels of as low as 100 mg/l may impart salty taste, although the usual taste threshhold is 400 mg/l. Higher levels of chloride increase oxidative corrosion rates.

Effects of chloride on aquatic life vary. Trout appear to be the most sensitive fish with reported harmful effects at 400 mg/l. Effects in general, however, often depend on the presence and amounts of other salts. Changes in natural chlorinity can exert harmful effects because of alterations in osmotic conditions.

The U.S. Public Health Service has set 250 mg/l Cl as a recommended upper limit to chloride concentrations for drinking water.

Observed Conditions

The Michigan Stream Control Commission carried out extensive chloride surveys of Saginaw Bay in 1935 and 1936. Fifty surveys were completed in that time. They reported concentrations ranging from as high as 350 mg/l at the mouth of the Saginaw River to as low as 3 mg/l in the open bay. In general, concentrations were highest in the vicinity of the Saginaw River ranging from 50 to 300 mg/l. No consistent distribution of chloride concentrations was noted. Higher concentrations did, however, tend to originate from the river and then follow the prevailing wind conditions. Because of changing wind conditions and natural bay currents, the degree of mixing and concentrations distribution at times seemed random. Average concentrations in the inner bay appeared to range from approximately 25 to 40 mg/l. Limited data was taken on the outer bay. Concentrations there averaged below 10 mg/l.

In the 1956 surveys (Beeton et al.), chloride concentrations ranged from greater than 280 mg/l at the mouth of the Saginaw River to 7 mg/l in the outermost bay (see figure 13). Chloride levels averaged 59.5 mg/l in the innerbay and 11.0 mg/l in the outer bay. High concentrations originated from the Saginaw River and appeared to flow counterclockwise around the bay. Higher concentrations were, however, also noted west of the river in two surveys. The spatial distribution of concentrations is heavily dependent on wind conditions. The prevailing westerly wind conditions promote a counter clockwise circulation.

Concentrations in the 1956 survey are generally larger than those found in the 1936 survey by as much as 20 mg/l in the inner bay and 5 mg/l in the outer bay. Precise comparisons are difficult because average concentrations were not available for the 1936 study.

The 1966 Lake Survey study of the outer bay reported concentrations from 3.4 to 20.4 mg/l. Concentrations varied by as much as 15 mg/l at specific stations. Sample locations were insufficient in number to observe any spatial distributions. Average concentrations ranged from 4 to 7 mg/l. No additional trends could be observed.

The July 1970 survey by The University of Michigan Great Lakes Research Division (GLRD) reported an average chloride concentration of 10.6 mg/l. The survey emphasized outerbay sampling and, therefore, did not reflect the overall bay average. No distribution data was available.

Michigan municipal intake water quality data was limited to just a few sampling points located within shore proximity. These data agreed with the previously reported data; observed concentrations ranged from 11 to 85 mg/l chlorides.

The most extensive chloride surveys of the bay have been carried out periodically by Dow Chemical Company, Midland, Michigan, since 1935. Limited amounts of the data were available in concentration color-coded maps. As previously demonstrated, concentration levels of chlorides varied widely in the bay with space and time. Heavy concentrations were always noted in the vicinity of the Saginaw River, and low concentrations observed in the outer bay. The distribution beyond this was heavily controlled by the prevailing winds. The predominant westerly winds resulted in heavier concentrations on the eastern portions of the inner bay, while south and easterly winds caused a clockwise concentration distribution. Changes in overall chloride levels with time were not easily observed because average concentrations were not available. From just gross observation it appears the levels have increased just slightly since the 1930's, although slight improvement has been noted in the 1960's.

In general, the Saginaw Bay is genuinely contaminated by chlorides from the Saginaw River. Levels have not reached the point at which they have proven to be toxic or offensive and are not in violation of any standards. Subtle effects may, however, have been exerted due to their influence. Distribution of chlorides is highly variable depending mostly on wind conditions.

Conductivity

General considerations

Conductivity is a measure of a solution's ability to conduct an electric current. It is reported as the specific electrical conductance, the reciprocal of the resistance in ohms of a one centimeter column of solution at a specified temperature. Pure water is itself an insulator. It is the presence of ions in solution that gives water its good conductivity characteristics. The higher the ion content or salinity, the greater is the conductivity. Conductivity is, therefore, an indirect measure of salinity. This characteristic is important because all aquatic organisms have adapted themselves to specific conditions of salinity which exert a specific osmotic pressure. They can tolerate small changes in the relative amounts of salts but not the overall concentration. Large changes in salinity will effect osmotic conditions and can result in ill effects for aquatic fauna.

Observed Conditions

In the 1956 synoptic surveys (Beeton et al., 1967) conductivity ranged from a high of 825 µmhos in June near the mouth of Saginaw River to less than 200 µmhos at the mouth of the bay, all taken at 18° C. (See figures 11, 15, and 16). Conductivity was generally higher on the eastern side of the bay with a decreasing gradient towards Lake Huron proper. The average inner bay conductance was 553 µmhos, decreasing to a 270 µmhos average for the middle and outer bay. The August 10 and October 30 surveys also showed higher conductivities in the southern end of the bay decreasing outward. On these dates, the respective average specific conductance was 463 µmhos and 391 µmhos for the inner bay, and 253 µmhos and 237 µmhos for the middle and outer bay. The latter two surveys did not show a significant spatial pattern of conductivities other than that already noted. Wind conditions probably caused a mixing of the surface waters (from which the samples were taken), masking any general circulation pattern.

In the 1956 surveys, higher conductivities were noted in the June 7 survey, decreasing in August and again decreasing in October.

This trend similarly appears with regard to the majority of the ionic parameters and again is attributed to variability in stream flow and dissolved solids loading.

Conductivity measurements were not taken in the 1935 Stream Control Commission Survey, so no trends can be documented. The 1966 Lake Survey data reaffirms the specific conductivities found in the very outer bay by Beeton et al. (1967). Their data demonstrates an average of about 200 μmhos. A July 1970 survey by the Great Lakes Research Division of The University of Michigan found an average conductivity of 247 μmhos at 25° C for the middle and outer bay. This Compares with the average of 270 μmhos and 253 μmhos (at 18° C) found by Beeton in June and August of 1956. Considering this limited data alone, the specific conductivity of the bay has not increased in the last 15 years.

Dissolved Oxygen (D.O.)

General Considerations

All living organisms are dependent on oxygen in one form or another to maintain their metabolic processes. The majority of processes in a "healthy" lake are aerobic and require free dissolved oxygen. For this reason the measurement of dissolved oxygen has become a standard for assessing the conditions of natural waters. Low levels of oxygen can result in the death of fish and other aquatic biota. If the level has not reached this critical point, harmful effects may still be manifested by disruption of the growth, development, and strength characteristics of the organisms or their eggs and young. Different organisms have various tolerances to low levels of dissolved oxygens. Michigan has set the following water quality standard to preserve aquatic life. For intolerant warmwater fish, average daily D.O. value should not be less than 5 nor should any single value be below 4 mg/l; for intolerant coldwater fish not less than 6 mg/l at any time; and for tolerant warmwater species an average not less than 4 nor any value less than 3 mg/l.

Oxygen levels are regulated by physical, chemcial, and biological processes. Oxygen enters into the water through two avenues, photosynthetic activity and diffusion from the air. It is removed primarily through the respiration of bacteria in the stabilization of organic matter (BOD), the respiration of other animal and plant life, and also the chemical oxidation of material in the water. The saturation or equilibrium concentration of dissolved oxygen is regulated by atmospheric pressure, water temperature, and salinity. The saturation concentration increases with the atmospheric partial pressure of 0_2 and decreases with salinity and temperature. Increases in temperature also increase respiratory rates and, hence, indirectly lead to faster oxygen depletion.

In general, oxygen levels can vary widely both vertically and horizontally depending on the physical, chemical, and biological conditions. It is, therefore, often used as a water quality indicator.

Observed Conditions

Beeton et al. (1967) measured dissolved oxygen only in the middle and outer zones of the bay during the ice-free months of

1956. They found oxygen levels to vary with temperature as theory would predict. The degree of saturation increased with higher wind and mixing conditions. D.O. concentrations ranged from 6.3 to 11.7 ppm with an average concentration of approximately 9 ppm. Percent saturation varied but rarely dropped below 90%. The lowest value of 66% was isolated. It occurred in June in the middle bay area at bottom depth. Percent saturation values appeared to decrease slightly in the fall, dropping a couple percentage points, despite the decreasing temperature. The probable explanation is the fall die off of phytoplankton and their subsequent stabilization by bacteria. The lower waters in the very outer bay demonstrated higher dissolved oxygen levels, than in the inner bay. An influx of the colder, oxygen-rich Lake Huron waters is the probable explanation.

The 1966 Lake Survey data revealed D.O. levels parallel to those found in Beeton's study. Similar seasonal and spatial trends were measured. Unfortunately this data also pertained only to the outer bay.

The only significant source of oxygen data for the inner bay is contained in a preliminary study by the Michigan Water Resources Commission from a 1965 survey (see figures 17 and 18). It documented near 100% saturation for all surface waters in the inner bay and 93-100% saturation in the middle and outer zones (July and August 1966). Bottom saturation levels averaged 95% in the outer bay and approximately 80% in the inner bay. The lowest point of saturation occurred opposite Pt. Au Gres where saturation values fell to 75%.

A July 1970 survey of 6 stations in the bay by the Great Lakes Research Division of The University of Michigan reported near saturation concentrations of oxygen at all stations. Saturation levels did, however, decrease slightly with depth, dropping to as low as 92% in near bottom samples.

In general, it can be concluded that the BOD and sediment demand of the bay have exerted slight effects on the oxygen content of the waters. The reduction in D.O. has not yet, however, reached the point at which it is harmful to aquatic organisms. The surface D.O. concentrations have remained sufficiently high to meet all Michigan water-quality standards, even for the fish and wildlife classification of intolerant coldwater fish species (76.0 mg/l). The shallowness of the bay allows sufficient mixing of the bay waters to keep the water column well oxygenated during the ice-free months. No data for D.O. conditions under the winter ice cover was available.

Hydrogen Ion Activity

General Considerations

The concentration of the hydrogen ion in a solution is generally expressed in terms of the pH which is the negative logarithm of the concentration. The pH is a measure of the intensity of the acid or alkaline conditions of a solution and is a master control parameter that governs such phenomena as solubility, degree of dissociation, and acid base equilibrium. It can severely effect the toxicity of chemical species in the water as well as the productivity and viability of aquatic organisms.

The Michigan water quality standards for all uses generally require a pH of between 6.5 and 8.8 with an induced variation of no more than .5 units.

Observed Conditions

In the 1956 surveys of Saginaw Bay, Beeton et al. (1967) found that the changes in pH of the surface waters followed the same trends in all areas of the bay. They found the pH to increase from 7.9-8.1 in June to a high of 8.4 in July and then to decrease to lower values in the fall. They found similar fluctuations in the bottom shallow waters of the outer bay, but no such trend in the deeper waters. These fluctuations are possibly a manifestation of photosynthetic activity: the uptake of CO_2 increases the pH; and then the fall die off is followed by a production of CO_2 and drop in pH as the biomass is stabilized.

Beeton also found lower pH's (7.6-8.0) in the bottom waters of the outermost parts of the bay. They attributed this to the influx of Lake Huron waters and their associated lower pH.

The 1966 Lake Survey data showed a pH range from 6.99 to 8.48. This data demonstrated the same seasonal fluctuation that was found by Beeton et al. as well as the hypolimnic influx of Lake Huron waters. The pH values were of the same range as in 1956 and did not indicate any significant change.

A 1970 survey by Great Lakes Research Division of The University of Michigan specified an outer bay average pH of 8.46. This value appears to be elevated. (Other values measured for Lake Huron proper were also elevated as compared with a 1956 study of Allen (1964). The GLRD found average pH in Lake Huron of approximately 8.4 as opposed to Allen's value of 8.1. This indicates a possible methods error in the 1970 work or a less likely general increase in pH of Lake Huron proper.

No pH data was available from the 1936 Stream Control Commission study.

The pH's, in general, fell within a range tolerated by most aquatic organisms and did not demonstrate any severe fluctuations. They did not violate any drinking water or water-quality standards. The pH is, therefore, considered not to be a problem parameter in Saginaw Bay.

Magnesium

General Considerations

Magnesium is commonly found in natural waters as a divalent cation. Magnesium is a very active chemical and is very rarely found in the elemental form. All magnesium salts, with the exception of the hydroxide at high pH's, are very soluable. Magnesium is a significant constituent of hardness and is found in most natural waters. Sources include dissolution from soils and rocks (such as tolomite) and industrial and municipal discharges.

Magnesium has been reported to be lethal to fish at concentrations as low as 476 ppm. Low levels of magnesium below 100 ppm have shown no adverse effects towards aquatic life.

Observed Conditions

Magnesium levels were found(Beeton et al., 1967) to range from 7 to 15 ppm in their 1956 survey (see figures 12 and 14). In each of their surveys the magnesium levels were highest at the south end of the bay near the mouth of the Saginaw River. Beyond this point the waters are increasingly diluted by the Lake Huron waters (magnesium concentration of approximately 6 ppm). Slightly higher concentrations were found on the southeastern bay as compared to the southwestern portions. The distribution, however, was variable again probably due to wind conditions affecting the surface waters.

The 1966 Lake Survey limnological data showed magnesium concentrations from 6.3 ppm to 12.5 ppm but demonstrated no obvious trend. No magnesium data was available from the 1970 or 1936 surveys.

Nigrogen

General Considerations

Nitrogen is an essential nutrient to all life processes. It is a necessary constituent of all proteins. The aquatic chemistry of nitrogen is complex because of the varying valence states and forms nitrogen can be found in. Nitrogen occurs in natural waters in six major forms. It can be incorporated into biomass of which the suspended portion is normall termed particulate nitrogen. In this state the nitrogen usually has a valence of 3- and is incorporated into proteins. Organic nitrogen is also found in the soluble state and is appropriately named. The inorganic forms of nitrogen include nitrate, nitrite, ammonia, and nitrogen gas having valences of 5+, 3+, 3-, and 0 respectively. In nature, nitrogen is cycled through these various forms as plant and animal life carry out their metabolic processes.

The total concentration of nitrogen is significant when considering the trophic aspects of a lake, while the specific forms are important in evaluating responses of various types of organisms. Inorganic nitrogen is utilized by phytoplankton (some of which can fix atmospheric nitrogen) to synthesize biomass. The organic nitrogen is further consumed by bacteria or other heterotrophs and incorporated into more biomass or broken down into the inorganic forms.

Nitrogen enters the aquatic biosystem through nitrogen gas fixation, industrial and municipal wastes, runoff of artificial fertilizers and also the solublization of certain mineral deposits.

Nitrogen levels are often critical in control of nuisance algal growths. Various authors have reported levels of inorganic nitrogen above which excessive algal growth may occur. This level can vary, however, depending on the balance of other nutrients. Sawyer (1957) reported .3 mg/l to be that level, with an inorganic phosphorous concentration of .015 mg/l. Ammonia and ammonium salts have been shown to be toxic to aquatic life. The degree of toxicity is related to the pH which controls the dissociation of ammonium hydroxide. Higher pH's increase toxicity.

Observed Conditions

Despite the considerable importance of nitrogen as a nutrient contaminant to natural waters, very little nitrogen data has been taken in Saginaw Bay. Neither the 1956 or 1935 surveys of the bay measured any forms of nitrogen. The 1966 Lake Survey data measured soluable nitrate at all stations, but information was restricted to the outer bay. Concentrations ranged from 0 to 3.9 mg/l, using an unspecified method of measurement. Measureable concentrations were reported only in the spring and early summer outside of which all waters had concentrations below their detection limits. The lowest detectable amount of nitrate reported was .3 mg/l. No spatial trends were noted.

The 1970 Great Lakes Research Division survey noted an average concentration of nitrate in Saginaw Bay to be .042 mg/l, well below the apparent detectable range of the Lake Survey's methods (see Table 4). The 1970 GLRD survey's average concentrations showed concentrations increasing with depth. This may be an effect of phytoplankton uptake in surface waters and the subsequent breakdown and release in the deeper bottom waters. Ammonia nitrogen was also measured in the 1970 survey. The average bay concentration was .0259 mg/l. Ammonia demonstrated concentrations increasing with depth similar to nitrate. The average surface concentration was .020 mg/l as compared with the bottom concentrations of .033 mg/l.

Very limited information from a 1971 survey by the Canadian Center for Inland Waters indicated a maximum observed inorganic nitrogen concentration of .777 mg/l in the inner bay and a maximum concentration of .307 mg/l in the outer bay. No range or average values were available, except for the areas near the mouth of the bay where concentrations were approximately .2 mg/l.

Although the overall data is insufficient to confirm any definite trends,a few general speculations are possible. First, the nitrate concentrations are generally lower in Saginaw Bay than in Lake Huron proper where the concentrations of nitrate average about .150 mg/l (GLRD 1970). The bay average is .042 mg/l. This is a consequence of algal uptake, accelerated as a result of the excessive nutrients available, particularly phosphorous. Ammonia concentrations appeared to be somewhat higher in the bay region (average .0259 mg/l) when compared with the uncontaminated open waters (average .0126 mg/l). This again may be a result of higher biologic activity. The breakdown of proteins within the water column and in the low oxygen-containing sediments can release free ammonia. The general low levels of total inorganic nitrogen, at times below .050 mg/l, indicate a slight possibility of nitrogen limitation.

Phosphorous

General Considerations

Phosphorous, like nitrogen, is essential for all aquatic life. It is intimately involved in the energy storage and release systems of all organisms. Because of its role in natural and cultural eutrophication, phosphorous has become one of the most discussed chemicals in the aquatic environment. Although total agreement has not been reached concerning phosphorous' role, it is accepted that large quantities of phosphorous must be available to support algal blooms.

Phosphorous occurs in natural waters as a result of leaching from minerals and soils, agricultural drainage, municipal and industrial discharges, and degradation and release from organic matter. Once in a water system, its removal is controlled by associated adsorption and sedimentation processes, biological or cultural removal of phosphorous containing biomass, and natural transfer due to flushing.

It is generally acknowledged that ortho-phosphate is the form of phosphorous directly used by phytoplankton, although all forms of phosphorous represent potential sources of nutrients as a result of biodegradation and hydrolysis. In water the various phosphorous forms are differentiated as soluable reactive phosphorous, usually considered to be PO_4; soluable organic phosphorous; and particulate phosphorous or that incorporated into biomass.

Although excessive amounts of phosphorous can cause nuisance algal blooms with associated odors and indirect detrimental effects on fish and other aquatic life, phosphates themselves do not exert any toxic effects.

Studies of the productivity of 17 Wisconsin Lakes suggest a concentration of .01 mg/l of inorganic phosphorous as a maximum value permissible without the danger of support of undesirable growths. It should be noted, however, that algal growth may be controlled by numerous other nutrient and physical conditions as well.

Observed Conditions

In the 1956 survey (Beeton et al., 1967) average concentrations of .041 mg/l and .018 mg/l total phosphorous were reported in the inner, middle, and outer bays respectively. In the inner bay average concentrations were .045 mg/l during the June 7 survey,

.037 mg/l for the August 10 survey, and .042 mg/l in the October 30 survey. The respective outer bay average concentrations were .013 mg/l, .024 mg/l, and .016 mg.l. The spatial distribution of phosphorous was interesting because it did not follow the distribution of the other contaminant ions (see figures 12 and 14). Although concentrations were as usual high near the mouth of the Saginaw River (approximately .070 mg/l in all the surveys) and low near the mouth of the bay .010 mg/l,the remainder of the distribution was not as typical. Phosphorous concentrations often appeared equally high on both the east and west sides of the inner bay. Furthermore, a tongue of low phosphorous concentrations (.030 mg/l or less) was noted extending into the center of the inner bay from the outer bay. On the August 10 survey,high concentrations were found on the shore side areas of the outer bay increasing shoreward from .020 to .050 mg/l. These spatial trends are somewhat contrary to the distribution of other ions. It may be a consequence of phosphorous runoff from land areas surrounding the bay and phosphorous inputs from the bay's other tributary streams. Since a large portion of the land areas are agricultural, large amounts of nutrient runoff can be expected. This runoff would not include as high a concentration of other ions (calcium, magnesium, chloride, etc.) and, hence, would impart little effect on the Saginaw River's induced distribution of the ion contaminants other than phosphorous. It is unfortunate that the 1956 survey did not include nitrogen measurements which might have better verified this theory.

Lake Survey Center's 1966 survey reported outer bay orthophosphorous concentrations of 0 to .4 mg/l. Well over 80% of the samples were reported to have had concentrations below their detection limits. The lowest reported concentration was .1 mg/l. No spatial distribution was noted. Seasonally, concentrations appeared to be greater in the spring and fall approximately at the times of turnover. The data is, however, questioned since the reported concentrations of .100 to .400 mg/l are excessively high when compared with values reported by others in the bay and Lake Huron proper.

The GLRD's July 1970 survey reported average concentrations of .053 mg/l soluable reactive phosphate and .034 mg/l particulate phosphate for the middle and outer bay (see Table 4). Soluble reactive phosphorous concentrations ranged from .0005 to .020 mg/l, the higher concentrations in the inner bay. Both parameters appeared to decrease slightly with depth.

A 1971 survey by the Canadian Center for Inland Waters reported concentrations of total phosphorous averaging from .010 to .030 mg/l in the middle and outer bays for the months April through November. The concentrations showed an increasing gradient from Lake Huron to the southern end of the bay. Soluble reactive phosphorous was reported to range from .005 to .001 mg/l with the higher values also in the southern bay.

In general, the phosphorous levels as reported by the above mentioned surveys are sufficient to support excessive algal growths, given other conducive conditions. No conclusions can be drawn concerning the distribution of phosphorous within the bay except that the highest concentrations were reported near the Saginaw River outlet. The data was insufficient to determine any changes in overall concentrations with time.

Potassium

General Considerations

Potassium is a highly active metal and reacts vigorously with oxygen, hence, it is only found in the ionic or molecular form in nature. Its salts are highly soluble and it is quite conservative in nature. Sources for potassium include municipal and industrial discharges, irrigation waters, and leachment from soils and rocks.

Potassium is a necessary nutrient for algal growth but has never demonstrated to be a limiting factor in their natural growth. Potassium has not been shown to be toxic to any life at levels below 400 mg/l.

Observed Conditions

The 1956 Beeton et al. survey reported concentrations of potassium from 1 to 6 mg/l (see figures 12 and 14). Concentrations for the inner bay were highest in the June 7 survey (average 3.6 mg/l) and lowest in the October 30 survey (average 2.0 mg/l).

The total average for the inner bay was 2.9 mg/l and 1.2 mg/l for the outer bay. Higher concentrations were generally found near the southernmost end with the lowest levels at the mouth of the bay. The potassium distribution was found to parallel that of phosphorous. In both the August and October surveys small tongues of waters with lower potassium concentrations were found in the inner bay. In addition, in the October survey, high concentrations were found on the shoreward portions of the outerbay. This information reinforces the speculation that agricultural runoff can be significant, since potash (K_2O) is a major constituent of most fertilizers.

The 1966 Lake Survey Center data reports potassium concentrations in the outer bay of .1 to 1.5 mg/l. No spatial or temporal trends were observed in the 1966 data. No additional sources of data were available.

The potassium concentrations were, overall, high in the Saginaw Bay as compared with Lake Huron waters (.6 to 1.3 mg/l; Allen, 1964). Possible significant contaminant sources besides the Saginaw River include agricultural runoff from all land-surrounding areas.

Silicon

General Considerations

Silicon is the second most abundant element on earth, representing 28% of the earth's crust. It is, however, never found in the elemental form in nature but occurs as silica in sand or quartz and silicates in feldspar, kalonite,and other minerals. Silicon usually occurs in natural waters as silicon dioxide. It is associated with colloidal or suspended matter or incorporated into biomass. Silicon is an essential nutrient used in structural tissues of many algae, particularly the diatoms.

Observed Conditions

Concentrations of silicon reported from the GLRD July 1970 survey averaged 1.06 ppm as silicon dioxide (see Table 4). No spatial distribution was noted. A clear absence of surface silicon depletion indicates either high mixing conditions or more probably the low diatom activity of the Saginaw Bay in the summer months.

The 1966 Lake Survey information documented silicon dioxide concentrations ranging from .5 to 2.5 mg/l. No spatial or temporal relationships were observed. No other silicon data was available.

Sodium

General Considerations

Sodium is another active metal that does not occur free in nature. Its salts are very soluable in water and will remain so, hence, it is considered a conservative element limnologically speaking. Sodium may be of natural origin or may be introduced from industrial and municipal sources.

The sodium ion has been shown not to be toxic at levels normally found in fresh waters. Sodium chloride has been found to decrease the toxicity of certain metallic compounds towards fish.

Observed Conditions

Beeton et al. (1967), reported sodium concentrations ranging from 2 to 26 mg/l (see figures 11, 15, and 16). The average concentrations for the inner bay were 15.8, 16.2 and 11.6 mg/l for June 7, August 10, and October 30, 1956 respectively and, similarly, 4.3, 3.6, and 2.9 mg/l for the outer bay. The survey showed highest concentrations at the Saginaw River mouth decreasing to the Lake Huron background levels of 2-4 mg/l (Allen, 1964) in the outer bay. The June 7 survey showed higher concentrations in the southeastern portions of the inner bay hinting of a possible counterclockwise circulation. The August 10 and October 30 studies showed equally high concentrations on both east and west sides of the inner bay. A low concentration tongue of waters protruded into the center of the inner bay during the latter two surveys.

The 1966 Lake Survey study of the outer bay documented concentrations from 2.6 to 10.1 mg/l with an average of approximately 3 mg/l. No trends could be speculated from the data.

No additional sodium data was available. Overall high concentrations of sodium indicate definite contamination from the Saginaw River. The elevated levels, however, presented no threat to aquatic life.

Sulfate

General Considerations

The sulfate ion is one of the major anions occurring in natural waters. It is important in public water supplies because of its cathartic effect on humans at high concentrations (USPH standards restrict sulfates to 250 mg/l). Sulfate waters have tendencies to form scales in boilers and heat exchanges. Sulfates are also important to biologic activity. They are incorporated into many proteins and organic matter. Given low oxygen conditions, the sulfur can also be reduced to nuisance sulfides. Artificial sulfate sources include municipal and industrial discharges and air pollution.

Observed Conditions

The 1956 survey shows sulfate concentrations on June 7 ranging from 8 to 42 mg/l, on August 10 from 10 to 28 mg/l, and on October 30 from 8 to 20 mg/l (see figures 11, 15, and 16). The concentrations were highest at the mouth of the Saginaw River decreasing in magnitude towards Lake Huron proper. In the inner bay, concentrations were generally less in the central region increasing shoreward. The average concentration for the inner bay was greatest in the June survey (29 mg/l) declining in August to 22 mg/l and, finally, dropping to 16 mg/l in October. Average concentrations in the outer bay were found to be 12 mg/l, 12 mg/l, and 10 mg/l for the same dates.

In 1966 the Lake Survey Center reported concentrations from 12 to 37 mg/l for the middle and outer bay. No observable distribution was noted. Similar sulfate levels were found in the 1970 GLRD survey. They reported an average concentration in the bay of 12.8 mg/l, however, with a sampling emphasis on the outer bay.

In general, sulfate levels in the bay are greater than that of Lake Huron where the concentrations range from 7 to 17 mg/l. Saginaw River is an obvious contaminant source with reported concentrations of 70-115 mg/l (Dow Chemical, 1956). The sulfate levels are not detrimental at present to water quality.

Temperature

General Considerations

Temperature is a critical control parameter in aquatic systems. It regulates the seasonal stratifications and turnovers and effects the growth, productivity, and cycles of most aquatic organisms. Increasing temperature decreases gas soluability, particularly oxygen, and increases gross respiration rates and at times aquatic growth. This results in increases in oxygen consumption from the BOD and often nuisance growths of plant life. Changes in temperature can alter the normal growth, development, and spawning activities of certain organisms, often to the degree that they can no longer exist.

Michigan has set water quality standards for various water uses and ambient water temperatures. In general they stipulate a maximum temperature and an induced variation of no more than 10 or 15° F, depending on the water quality and usage.

Observed Conditions

Temperature data was available from 5 stations in Beeton's 1956 study, all stations in the 1966 Lake Survey study (outer bay exclusively), and from Michigan Water Quality Municipal Intake data. They all document Saginaw Bay to behave thermally much like any midlatitude, fresh-water lake. Temperatures range from 0° C in the frozen waters, to 20-25° C. in the summer surface waters. Thermal turnovers occur in approximately May and October, where depth is sufficient for stratification (primarily only in the outer bay). The thermal effects of the Saginaw River could not be ascertained because of the lack of sufficient sampling stations in the inner bay and the unquantified effects of solar heating.

Studies performed by the Consumer's Power Company in 1970 and 1971 document the thermal effects of their cooling water discharges in the vicinity of the Saginaw River. A plume of surface waters with elevated temperatures (2° or more) often extended beyond 2 miles of the discharge area. Temperatures immediately at the discharge point were elevated frequently as much as 14° F. The size and intensity of the plume was significantly altered by wind conditions. These discharge responses represent possible violations of Michigan water quality standards.

The discharge area is primarily marsh in character but can still be adversely affected by thermal contamination. Effects may extend to the bay as a whole by restricting spawning activities of fish. No positive confirmation of these effects was found.

From very limited 1956 temperature data (Beeton et al., 1967) it appears that temperatures may have been higher in the inner bay than in the open lake for the same dates (see figure 10). If the difference does exist, the gradient would be at most a few degrees centigrade. A probable explanation is the generally shallower waters and contamination from tributary sources.

Trace Metals

Trace metals are important nutrient requirements for all organisms. Growth and development can be severely limited by the absence of one or more essential trace elements. It has been speculated that certain algal blooms may have been limited by trace metal requirements. Trace metals can also exert toxicity in very low levels to aquatic organisms. Despite their obvious importance, no source of information was available on trace metal concentrations for Saginaw Bay.

Investigations need to be made to evaluate their importance and examine for possible violations of water quality and drinking water standards.

Due to dredging and industrial activities, the trace metal concentrations in Saginaw Bay are speculated to be elevated from the background Lake Huron levels.

Transparency

General Considerations

Transparency is that quality of water which governs light penetration or extinction. It is typically measured in the field as a secchi disc observation or in the laboratory as Jackson Turbidimeter Units. It is important to aquatic life because it controls the magnitude of the euphotic zone and, hence, governs primary production. In certain eutrophic lakes, production can be limited by the energizing light rather than chemical nutrients.

Observed Conditions

The 1936 Saginaw Valley Report revealed Jackson turbidity figures ranging from 75 at the mouth of the Saginaw River to 2 in the open bay. Average figures in the open bay were approximately 10. No other Jackson turbidity figures were available from other sources.

The 1970 GLRD study reported an average transparency of 1.8 meters with sampling bias on the cleaner outer bay. This transparency is less than 1/5 that of the Lake Huron uncontaminated waters. No other transparency figures were available.

General Conclusions

The existing water quality of the bay area directly reflects the influence that human population concentrations and industrial activity has upon the basin. It is largely determined by the inflow from the Saginaw River which carries excessive quantities of waste material from industrial, municipal, and agricultural sources. These effects are apparent in the high dissolved solids content, particularly chlorides and nutrient enrichment. The distribution of these contaminants within the bay's surface waters is controlled primarily by wind conditions, and may shift from day to day.

Other sources of input into the Saginaw Bay other than the Saginaw River are minor. All other flows combined amount to significantly less than that of the Saginaw River flow. The discharges from the Au Gres and Rifle Rivers along the northwestern shores may have had a diluting effect on the concentrations of various chemical constituents in the bay. The low concentrations in the area, however, were more likely due to inflow of Lake Huron waters (Beeton et al., 1967). Higher concentrations of nutrients, specifically phosphorous and potassium, along the coastal portions of the bay indicate that agricultural runoff may be a significant source of contamination from all rivers and shore areas.

Overall, the physical-chemical data on Saginaw Bay is insufficient for effective analysis of trends both spatial and temporal. Except for the 1956 study by Beeton et al., the data lacks an adequate number and distribution of sampling stations. Complete analysis for nutrients and other relevant chemical constituents is needed and should be measured in surface and subsurface waters. Accurate statements concerning the circulation patterns within the bay and the distribution and effects of concentrations of chemicals cannot be made from surface data alone.

VI. Biological Considerations

Coliform

General Considerations

Natural waters can be carriers of pathogenic organisms. Because of difficulty in testing waters for pathogenic bateria, they are instead analyzed for coliform bacteria, which are considered to be an indication of fecal contamination. Coliform bacteria are themselves mostly not harmful; however, they are associated with pathogens because of their communal environment. High concentrations of coliform tend to indicate the existence of a potential health hazard.

Sources of coliform bacteria are land runoff, waste discharges, and any discharge that has come into contact with mammalian fecal material. Since coliform can originate from many sources other than human excreta, it has been suggested that additional parameters such as fecal coliform and fecal streptococci should be used for more precise evaluation. Agreement is not total; because of coliform's large historical databank and its familiarity to water testers, it is continued to be used as the premier bacteriological parameter.

The Michigan Water Resource Commission has set coliform standards for various uses of waters. For "total body contact" waters, the coliform levels are not to exceed 1000/100 ml. If the natural background coliform level is above 1000 then the fecal coliform analysis is to be used in conjunction. Fecal coliform counts are not to exceed 100/100 ml.

Observed Conditions

The principal source of bacteriological data is the Michigan Water Resource Commission's "Report on Bacteriological Quality of Michigan Surface Waters." Unfortunately, it represents sampling data only from near shore areas. Also, of the 18 stations sampled, there are none in the areas between the Saginaw River and Sand Point. In 1966 all mean total coliform concentrations were measured to be less than 1000/100 ml in the bay. The geometric means, representing anywhere from 5 to 72 samples, ranged from 151 at Point Lookout to 579 at Oak Beach (on the northwestern shore of the bay) with an average of around 200-250. In general, the 1966 concentrations are the same in Saginaw Bay as those found on the other Lake Huron coastal samples, except for isolated stations. The 1967 bacteriological data showed a marked increase in coliform. The northeastern shores of the bay showed mean concentrations averaging below 1000 with a range from 429 to 1617. The concentrations on the western shores were much higher, ranging from 688 to 5676. The 1968 data showed a similar trend, although ironically the 1967 station with the highest mean (Whitney Twp.) now had the second lowest mean of 287. Both 1967 and 1968 coliform concentrations were of the same magnitude as those found at other

Lake Huron stations. No identifiable, consistent spatial trends can be derived from the coliform distribution. The reported concentrations vary widely which may indicate highly variable contamination, variable mixing, or possibly poor testing technique.

The Michigan WRC has also performed fecal coliform testing since 1967. These data indicate that mean concentrations from the bay are generally well below 100/100 ml. They averaged about 20-25 with the means ranging from 10 to 216. No spatial or temporal trends were observed.

Overall, the bacterial concentrations in Saginaw Bay are comparable to those found in the majority of Michigan's eastern coastal waters. Although the total coliform counts indicate that the waters are unsatisfactory to allow unmonitored total body contact, the fecal coliform counts indicate safe conditions. The high coliform levels do present problems, however, to water treatment operations. They require more intensive treatment and chlorination and restrict the lengths of filter bed runs.

Benthic Fauna

General Considerations

Analysis of benthic microinvertebrate communities has proven to be a valuable tool in evaluating water quality. Changes in populations or community composition can indicate changes in environmental conditions. These effects may result from primary environmental changes affecting the survival and reproductive capabilities of individual species or indirectly from interaction with associated organisms.

Benthic organisms are often classified into three basic groups: tolerant, intolerant, and facultative. The tolerant organisms are considered to be those that can survive and flourish best in enriched or polluted environments. Intolerant organisms are sensitive to environmental stress and usually are not found in polluted environments. Facultative organisms can survive in a wide variety of conditions. By examining the distribution and populations of these classes of organisms, both spatially and temporally, conclusions can often be drawn concerning changes in water quality.

Observed Conditions

Information concerning the benthic invertebrates of Saginaw Bay are available from primarily seven surveys: The Michigan Water Resources Commission in cooperation with Dow Chemical Company carried out surveys in 1953, 1954, 1955, and 1965; the Michigan Department of Conservation and the U.S. Fish and Wildlife Service were responsible for a very thorough survey in 1956; in 1965 under the Great Lakes - Illinois River Basins Project of the FWPCA benthic investigations were conducted on all of Lake Huron; and in 1970 a study was conducted by the Great Lakes Research Division of the University of Michigan.

Overall, the bottom fauna of Saginaw Bay includes specie representatives from several taxonomic groups. The most prominent forms are oligochaetes and amphipods. The following general observations can be made:

1. The Saginaw River has restricted benthic fauna in the inner bay to predominantly pollution tolerant organisms, especially along the south and southeastern coasts.

2. Other tributaries to the bay do not appear to have limited benthic fauna. They may, however, have increased biomass productivity locally.

3. The oligochaetes are the dominant organism in the inner bay. Their populations have increased significantly in the past 15 years with present levels in the inner bay now ranging from a low of 500/m^2 in the Coreyon Reef to a high of 25,000/m^2 at the mouth of the Saginaw River. Distribution may be related to bottom type.

4. Amphipods are dominant in the deeper outer bay with the common genus changing from Pontoporeia to Gammarus southward.

5. The mayfly, Hexagenia, once common is no longer found in the bay.

In general, although the productivity of the Saginaw Bay has increased in the last 15 years by estimates anywhere from two to sixfold, the data does not definitize any changes in water quality. Positive statistical correlation of benthic distribution was not possible. The trends observed in the bay have, however, been paralleled to those in western Lake Erie. Comparisons between studies is difficult because of different sampling stations and sampling methods.

The earliest studies were carried out by the Michigan Water Resource Commission in 1953 and 1954. The sampling emphasized the perimeter of the inner bay. Both studies demonstrated similar benthic resources. Tubificids (aquatic earthworms from the class Oligochaeta) comprised the major portion of all samples. They made up 62% of the total number of organisms in the July 1954 study during which time the genus Limnodrilus was most prominent (69% of the Tubificids). The average number of bottom organisms present in 1954 was 279 per square foot (approximately 3000/m^2), an increase from 239 in 1953. Tubificids were in greatest numbers at the mouth of the Saginaw River and along the southeastern shores. A chi-square test was used to verify the significance of the higher concentrations of tubificids on the eastern side of the bay. This distribution may be attributed to the organic loading of Kawkawlin River, the Saginaw River with its prevailing northeasterly flow, and the discharges of the sugar beet and milk plants in Sebewaing area.

Cleanwater species were poorly represented in the 1954 samples. Of the 17 samples taken they were absent or in quantities less than 1% in 7 samples. The sampling stations were located near the mouth of the Saginaw River and along the southeastern shore. Cleanwater species average 6.0% at each station. Only 3 samples had over 10% cleanwater organisms, two of which were in the outer bay. Interestingly enough, the third with 27.4% cleanwater species was located 6.5 miles northeast of the Saginaw River mouth. The prominent species there was Eurycercus lamellatus, a crustacean.

Other prominent invertebrates in the 1954 survey included blood worms, *Chironomus plumosus*, and the burrowing mayfly *Hexagenia limbata* which was found abundant at several stations. Both were judged to have emerged just prior to or during the survey due to the abundance of floating exuviae.

The June 1955 WRC survey sampled 19 stations in the bay. The pollution tolerant tubificids were still dominant, representing 63% of all the organisms. The average number of organisms per square foot increased 17.3% over 1954. In general, the benthic conditions seemed to be improved. The average number of species per sample increased from 8.7 in 1954 to 10.4 species per sample in 1955. Although tolerant species were dominant, cleanwater species were not present in all but 4 samples. The mean station percentage of cleanwater organisms was 13.1%. Ten of the samples had communities in which over 10% of the organisms were cleanwater invertebrates (5 were over 20%, the highest being 66.5%). The cleanwater midge larvae *Cryptochironomus digitatus* was also found in over 50% of the samples.

The validity of this pronounced increase in water quality as indicated by the benthic fauna is, however, questioned. Due to the high variability of the Saginaw Bay sediments and the absence of duplicate samples, this author doubts that any increase in water quality can be documented, particularly within a one-year period. It also appears from the bottom description that the 1955 benthic samples were taken from locales that were generally more sandy in nature as compared with the 1954 samples, which were described generally as muddier. It can be concluded, that the problem area in both studies was between the Kawkawlin River and Sebewaing. Low numbers of cleanwater organisms and high concentrations of tubificids were found in these areas.

In 1956, 1000 bottom samples were taken from Saginaw Bay between June 1956 and March 1957. Schneider, Hooper, and Beeton reported the major results of this study in 1969, while Brinkhurst reported specifically on the oligochaetes in 1967. The average standing crop of benthic invertebrates found from this survey was 4.43 g/m^2, in contrast with an estimate of 15.1 g/m^2 for the 1955 WRC survey. The comparison is marginal, however, because of different station distributions. The 1955 study included only 3 of 19 stations in the outer bay while the 1956 study had 11 of 51, that also included deep water stations, unlike the 1956 study.

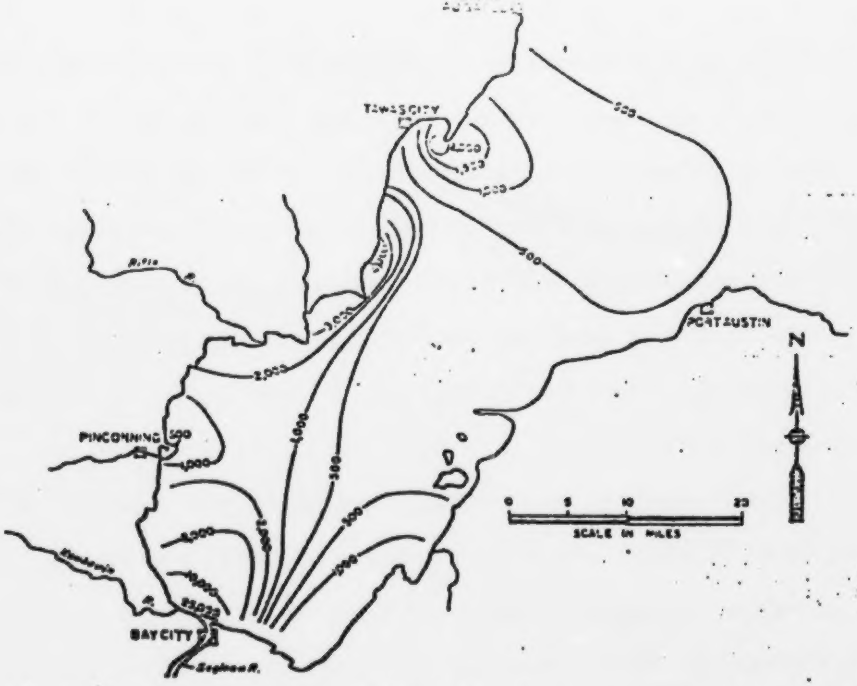
Schneider et al., found it difficult to statistically associate distribution of benthic fauna with other water quality parameters. Some relationships were still observed. Highest biomass production was noted in the southern third of the bay (4.72 g/m^2). Lowest productivity was in the outer third of the bay (3.46 g/m^2). Areas of highest biomass included the deeper waters of the inner and outer bays and Wild Fowl Bay. The shallow and sandy Coreyon Reef was the least productive. Among all the stations, oligochaetes and chironomids were most prominent, comprising two-thirds of the total number of organisms. The oligochaetes constituted over 50% of the crop in the southern third of the bay, but distribution within the bay appeared to be mostly haphazard. The highly tolerant oligochaet, Limnodrilus hoffmeisteri, was again prominent in the southernbay and appears to correlate well with the known flow of the Saginaw River, along the north and south shore depending on wind direction.

Amphipods, particularly Pontoporeia, were predominant in the outer bay with highest concentrations in the deepest stations. The variation in numbers appeared to be correlated with depth. Other organisms found include chironomids and mayflies which made up the majority of the biomass in the middle third of the bay area. The amphipod Gammarus was also common. Oligochaetes made up 22% of the biomass, 54% in number. Sphaeriid clams were noticably rare as compared with the 1965 study.

In 1965 the WRC followed up their previous work with another study including 43 stations. They concluded that the benthos did not indicate any significant changes in water quality since the 1954 and 1955 surveys. The bottom samples demonstrated similar distribution of indicator organisms. Oligochaetes were again dominant, particularly in the inner bay, comprising from 18% to 99% of the total number of organisms. Midge larvae made up the majority of insect population that was found. In contrast to the earlier WRC studies, but in agreement with the 1956 survey, the cleanwater mayfly, Hexagenia limbata, was not found. In all, 50 different kinds of organisms were identified. The investigator in this study concluded that "water from the Saginaw River limits the bottom life to pollution tolerant forms in an area from the river mouth to the deep water off Point Au Gres and includes the shallow southeast protion of the bay southwest of fish points." He further classified the shallow north side of the bay as a facultative environment and the outer bay a cleanwater environment. The main source of pollution to the bay was attributed to the Saginaw River. All other tributaries, including the Kawkawlin, Rifle, and Au Gres Rivers, exerted no limiting effects on the fauna. For example, diversity was found to be greater at the mouth of the Kawkawlin River than at stations both north and south of the river.

The FWPCA 1965 survey (Schuytema and Powers, 1966) (figure 19) again documents what now appears to be the prominent distribution. Oligochaetes were the most numerous organisms found in the bay, comprising 78% of the total population. Oligochaete concentrations were higher in the western portion of the inner bay (average 2-4000 organisms/m^2) than in the eastern portions (average < 1000 because of differences in bottom type. Although only 8% of the organisms in the bay were amphipods, they dominated the outer bay samples. Pontoporeia affinis was the dominant amphipod at the mouth of the bay, while in the middle bay Gammarus predominated.

An interesting comparison of the WRC 1955 survey, the 1956 survey, and the Schuytema and Powers 1965 survey was made by Schneider et al. (1969). In 1956, a die off of



Mean populations of oligochaetes in Saginaw Bay, numbers/m², April-September 1965.

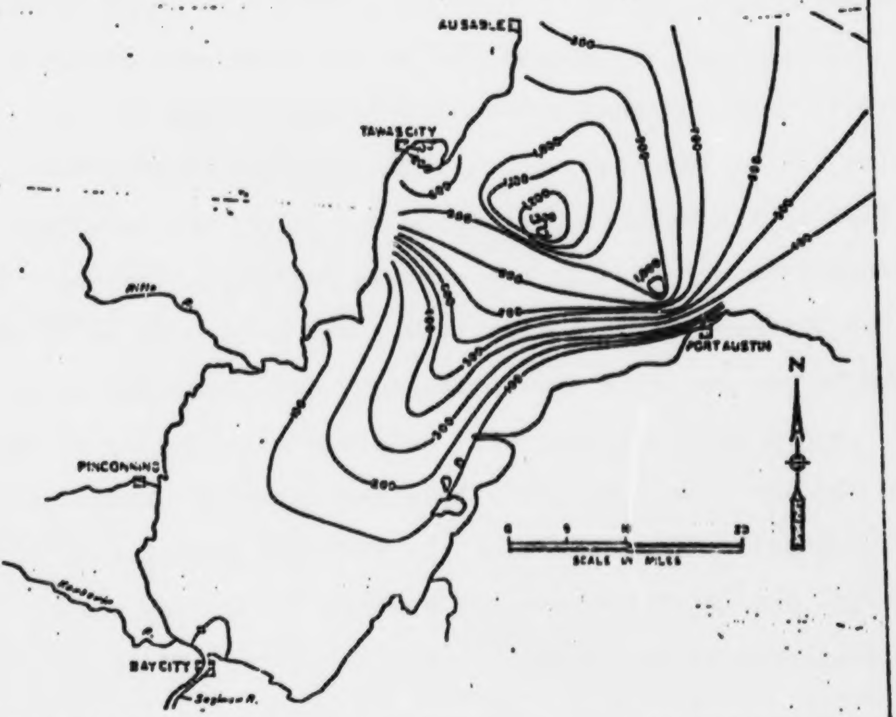


Figure I9 . Mean populations of amphipods in Saginaw Bay, numbers/m², April-September 1965

source: Schuytema and Powers 1966

both mayflies (Hexagenia) and fingernail clams was observed. The clam population recovered by 1965, but the mayflies did not. This indicated some catastrophic event occurred in 1955 or 1956 from which only the clams were able to recover. A comparison was drawn to the mayfly die off in western Lake Erie causedby low dissolved oxygen. High turbidity could have also been a factor, however, in Saginaw Bay.

The most recent benthic study was the 1970 survey of 7 stations in the bay by GLRD of the University of Michigan. They did not document any new trends. Amphipods were still predominant in the outer bay with the dominance changing from Pontoporeia to Gammarus southward. Oligochaetes were as usual found to flourish. The outer bay stations had standing crops of 400-1700 organisms/m^2 while the inner and middle bay stations showed higher numbers, 3200-6000 organisms/m^2. The once prominent mayflies were not collected. The GLRD observed an increase in oligochaete populations from 1965 to be as much as sixfold, ignoring sampling bias.

Detailed studies of the specific regions near the Saginaw River and Quinacassee Bay have been carried out for Consumers Power Company since 1970. Thermal discharges from the Kearn-Weadock power plants near the Saginaw River restricted the already limited benthic populations within a 1/2 mile radius of the discharge. The thermal discharges from the Kearn-Weadock power plants were suggested to have limited the population densities within this range. At an intermediate distance from the discharge (1-2 miles) oligochaete populations were observed to increase, reflecting a diminished yet existing thermal effect, since sensitive organisms were still repressed. Beyond a three-mile radius, worm densities were noted to decrease while more sensitive organisms (chironomids) were noticed to increase in population. This reflects a partial return to normal biological conditions.

The benthic invertebrate fauna at the Quinacassee site was found to include primarily midges and oligochaetes. Population densities were low, averaging less than $250/m^2$. This is attributed probably to the bottom type, a sand and gravel constituency.

The Michigan WRC has also carried out studies on the Sebewaing Bay area which receives discharges from two industries, a sugar company, and a dairy. In general, they found in 1970 primarily oligochaetes and midges. This is in contrast with a 1957 WRC study which found other organisms in addition, including leeches, fingernail clams, snails, scuds, mayflies, caddisflies, and other dipterian species. The average number of species per sample dropped from 10.4 to 3.5. According to the WRC, "these data reflect a gross change in the quality of Sebewaing Bay over the last 13 years. The decline in species. . .indicates a serious degradation of environmental quality. This degradation is a reflection of the general decline in Saginaw Bay water quality. Organic discharges to Sebewaing Bay such as those of the Michigan Sugar Company are strong influencing factors."

Plankton and Macrophytes

General Considerations

Plankton and macrophytes together constitute the base of the entire aquatic food web. They are the primary producers and primary consumers in all aquatic ecosystems. Plankton are small, free-floating organisms found in natural waters. They include both plant and animal life and are usually divided into two classes, phytoplankton or algae and zooplankton. Phytoplankton are primary producers and are the main source by which light energy is incorporated into aquatic biomass. Zooplankton can be considered to be the next link in the food chain, feeding on phytoplankton. They are often termed primary consumers. Both are grazed on by higher aquatic organisms. Because of their elementary association with the physical and chemical characteristics of the water, they are affected by changes in water quality. Their populations, growth characteristics, and species composition are often used to evaluate the state of water quality. Changes in their characteristics can generate other changes higher up the food chain.

Macrophytes can be described as aquatic plants. These may be rooted in the sediments or floating. They, like phytoplankton, are important because they are primary producers. They are autotrophic and can incorporate inorganic materials and light energy into organic biomass. Besides their role as a primary producer, they are significant as "nutrient pumps" returning nutrients from the sediments back to the water column as biomass.

Observed Conditions

Little significant work is available on Saginaw Bay phytoplankton. What information was found indicates very high productivity in the bay. Limited amounts of data were available from the 1970 University of Michigan GLRD survey. It documented algae levels averaging 7.26 mg/l as chlorophyll a at 3 meters. This concentration is 8 to 9 times the level found in the Lake Huron proper. Carbon fixation measurements showed similar high productivity, 31±23 $mgC/m^3/hr$ at 0 meters and 28±17 $mgC/m^3/hr$ at 3 meters. (These values are means from 5 samples with the figure following the ± indicating a standard deviation). The highest fixation rates were found in the innermost bay stations. The mean values showed productivity to be anywhere from 15 to 30 times that measured in the open lake. The mean assimilation rate was 4.16 mgC/hr/mg Chl a, 1 1/2 to 3 1/2 times greater than the Lake Huron ratio. This may be a reflection of the low nitrate, high phosphate conditions in the bay.

Taxonomic analysis of the bay's phytoplankton show significantly fewer diatoms than in the open lake. *Ceratium* was the dominant genera, common or abundant at five of their six stations. *Microcystis* was common or abundant at four stations. *Aphanizomenon* and an unidentified organism, possibly a blue-green but also possibly a sulfur reducing bacteria, were common at the three middle bay stations.

An additional source of phytoplankton data was a 1972 survey by the CCIW. Chloryphyll a levels were found to average from

4 to 12 mg/l Chl a with the higher values in the inner bay. Concentrations at times ranged as high as 20 mg/l. This data agrees well with the GLRD report. No taxonomic data was available.

Limited studies were done by Beak Consultants Inc. for Consumers Power Company in 1970 and 1972. Sampling stations were primarily along coastal zones (within 3 miles of shore) from Pinconning to Sebewaing. In 1970 only plankton volumes were taken averaging 4 mls/m^3 of strained lake water. In 1972 taxonomic studies were undertaken on phytoplankton. Populations were typically quite diverse. Diatoms were not well-represented, although Fragilaria was present at all stations. The dominant greens were Ulothrix and Pediastrum, although large masses of Microthamnium were found in the marsh areas not sampled. Ceratium was repsesented well at all stations.

Data concerning the macrophytic populations was scarce, the only source being the previously mentioned Beak Consultant studies. Sampling was, however, only carried out in the areas southeast of the Saginaw River, near the locale of the Kearn-Weadock power plant discharge. Ten macrophytic families were identified. They were, Ceratophyllacea (coontails), Cypheceae (sedges), Gramineae (grasses), Juncaceae (rushes), Lemnaceae (duckweed), Najadaceae (naiads), Plantaginaceae (plantains), Potamogetonaceae (pondweeds), Salicaceae (willows), and Typhaceae (cattails).

Information on the zooplankton communities was restricted to the limited 1970 GLRD study. Settled volumes of zooplankton did not indicate degraded water quality. The mean volume was .67 ml/m^3, slightly below the mean found in the open lake. In the outer bay *Bosmina* and *Asplanchna* were most abundant with *Diaptomus*, *Cyclops*, and *Leptodora* less abundant. In the middle and inner zones of the bay an unidentified rotifer was predominant. *Bosmina*, *Diaptomus*, *Daphnia*, *Asplanchna*, and *Cyclops* were common. No authoritative water quality statements can be drawn from this data, although the rotifer and *Bosmina* population distributions indicate possible eutrophication.

Fish

General Considerations

Fish is a valuable direct aquatic resource for man and is harvested commercially and by individual sportsmen. It also represent a major element in the recreational potential of an aquatic system. Millions of dollars are spent annually on sport fishing activities. Fish populations and species composition are, hence, carefully monitored by both industry and sportsmen. Changes in fish populations can be a result of numerous factors including: changes in water quality affecting fish directly; changes in water quality which disrupt the food chain and affect fish indirectly; exploitation; uncontrolled natural or introduced predation; changes in the physical character of the ecosystem disrupting the spawning or growth cycles, etc.

Observed Conditions

Traditionally Saginaw Bay has been a prominent commercial and recreational fishing resource. Over 90 species have been recorded in the bay, including lake herring, smelt, chubs, white sucker, channel catfish, yellow perch, walleye, whitefish, lake trout, bullheads, rock bass, carp alewife, small mouth bass, northern pike, rainbow trout, coho salmon, and numerous forage and non-commercial fish.

Commercial fishing became an established industry in Saginaw Bay in the mid 1800's in response to the expanding population and onset of the industrial revolution. Fish production rapidly rose in the 1800's, and peaked in 1902 with a fantastic 14,182,000 pounds of production. The fish production has, however, decreased gradually since then to a low of 2,557,000 pounds in 1966. No reversal in this trend is foreseen. The decline has been the result of changes in species composition which was brought about by a combination of factors. These include sea lamprey and alewife disruption, exploitation, pollution, and habitat changes. Economic squeeze has also taken its toll with increasing costs often restricting a profitable harvest.

The principal source of information on Saginaw Bay's fish resources originate from the Fish and Wildlife Service of the U.S. Department of the Interior. Two very useful studies were published: "Fluctuations in Commercial Fisheries in Saginaw Bay 1885-1956" and "Fish and Wildlife as Related to Water Quality in the Lake Huron Basin." Numerous other studies have been carried out on the bay's fish resources, but they are on more specific topics such as: the fluctuations in growth and year class strength of walleyes; food of the American smelt; and fluctuation in populations of yellow perch. All these studies indicate the same conclusions, that the fish resources in the Saginaw Bay have been severely altered in the last century and that the commercial fish industry there is endangered.

Prior to 1930 no dramatic alterations in the fish community had been noted. Lake herring was the dominant species with catches ranging from 1 to 8 million pounds. A typical catch in that period was 3 to 4 million pounds per year. Walleye, yellow perch, and suckers were also abundant, each amounting to approximately 1 million pounds per year. Whitefish and lake trout, although not as abundant, were still very valuable resources with typical productions of 50,000 and 30,000 pounds per year respectively. The two most significant occurences in this period were, however, the appearance of carp and the decline of lake sturgeon. Carp, introduced to the U.S. in 1874, amounted to approximately 10% of the catch by 1918. The decline in lake sturgeon,from 81,000 pounds in 1885 to practically nothing in 1928, was attributed to an intensive effort to remove sturgeon from areas where they damaged gear used to fish for other species.

Beginning in about 1930, dramatic changes in species production were realized, and the consequential decline in fish production was observed (see Tables 5 and 6). Lake trout was the first species to be affected. Because of the variability in the areas included in the reported statistics, the lake trout catch appears

Table 5 source: Fish and Wildlife Div. Dept. of Interior 1969
Average U. S. Commercial Fishery Production for Specified Periods of Nine Major [illegible]
Species in Saginaw Bay and Lake Huron Excluding Saginaw Bay.

	(Thousands of Pounds)								
Species	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965	1966
Carp									
Open Lake	25	45	163	146	211	63	68	40	62
Saginaw Bay	925	794	729	1409	1247	1420	1343	1384	769
Catfish									
Open Lake	-	2	10	6	8	5	3	1	2
Saginaw Bay	45	102	340	249	248	311	201	145	164
Chubs									
Open Lake	517	256.	141	133	120	850	2086	1326	802
Saginaw Bay	tr	tr	tr	tr	3	74	247	21	5
Herring									
Open Lake	927	1056	563	496	417	41	17	42	16
Saginaw Bay	2901	3823	1827	1003	1098	87	23	tr	tr
Lake Trout									
Open Lake	1639	1350	602	42	tr	tr	tr	-	-
Saginaw Bay	260	75	74	4	tr	-	-	-	-
Suckers									
Open Lake	852	846	491	473	236	66	48	36	14
Saginaw Bay	1305	849	809	889	904	540	484	353	299
Walleye									
Open Lake	169	174	100	101	108	74	63	76	34
Saginaw Bay	1173	1379	1501	411	64	62	59	25	17
Whitefish									
Open Lake	2112	918	127	943	123	59	225	172	171
Saginaw Bay	1282	116	19	507	11	3	47	3	1
Yellow Perch									
Open Lake	101	148	90	56	69	98	189	71	97
Saginaw Bay	517	606	530	394	376	319	375	895	1221
TOTAL (All Species)									
Open Lake	6410	4880	2359	2450	1348	1311	2743	1788	1212
Saginaw Bay	8602	7837	5891	4964	4178	3023	2944	2885	2557

Table 6 source: Fish and Wildlife Div. U.S. Dept. of Interior 1969

Percentage Composition by Major Species of U. S. Commercial Fishery Production for Specified Periods in Saginaw Bay and Lake Huron Excluding Saginaw Bay*

Species	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965	1966
Carp									
Open Lake	tr	1	7	6	16	5	2	2	5
Saginaw Bay	11	10	12	28	30	47	46	48	30
Catfish									
Open Lake	tr	1	6	5	6	10	7	5	6
Saginaw Bay	tr	1	6	5	6	10	7	5	6
Chubs									
Open Lake	8	5	6	5	9	65	76	74	66
Saginaw Bay	tr	tr	tr	tr	tr	2	1	1	tr
Herring									
Open Lake	14	22	24	20	31	3	1	2	1
Saginaw Bay	34	49	31	20	26	3	1	tr	tr
Lake Trout									
Open Lake	26	28	25	2	tr	tr	--	--	--
Saginaw Bay	3	1	1	tr	tr	--	--	--	--
Suckers									
Open Lake	13	17	21	19	17	5	2	2	1
Saginaw Bay	15	11	14	18	22	18	16	12	12
Walleye									
Open Lake	3	4	4	4	8	6	2	4	3
Saginaw Bay	14	18	25	8	2	2	2	1	1
Whitefish									
Open Lake	33	19	5	38	9	tr	8	10	14
Saginaw Bay	15	1	tr	10	tr	tr	--	tr	tr
Yellow Perch									
Open Lake	2	3	4	2	5	7	7	4	8
Saginaw	6	8	9	8	9	10	13	31	48

*Percentages do not sum to 100 due to rounding.

to have increased to an average catch of 260,000 pounds for 1930-1934. This increase may or may not be actual. What is definite, however, is the significant decline thereafter in lake trout resulting from the introduction of the predatory marine sea lamprey. The average production for the period from 1935 to 1944 was 1/3 to 1/4 of earlier catches. By 1950 the lamprey had taken its toll; trout were no longer a viable commercial fish catch, recorded to be only caught in traces. Since 1955 zero commercial production of lake trout has been recorded.

Whitefish demonstrated an even more catastrophic decline. In the period 1930 to 1934 whitefish constituted 15% (1,282,000 pounds per year) of the total Saginaw Bay catch. Exploitation in this period, through use of the deep trap net, resulted in a decline in production to 116,000 pounds per year from 1935-1940 and 19,000 pounds per year for 1940-1944. Restrictions placed on the deep trap net in 1935 did not, however, stop the decline, and predation by sea lamprey was now the controlling factor. A brief upturn in catch occurred in 1946-1948 due to a strong 1943 year class, but, aside from then, the valuable whitefish are now scarce. In 1966 only 1000 pounds of whitefish were caught

Walleye production in Saginaw Bay fluctuated without a long-term trend until the 1940's. Between 1930 and 1940 the production had risen to over 1 million pounds in all years except 1931. Walleye represented from 7 to 21% of the total catch. After 1943, production began to decline progressively. In 1966 walleye production represented only 1% of the total Saginaw Bay catch, a production of just 17,000 pounds. The decline has been speculated to be a result again of sea lamprey predation.

Smelt landings up until 1941 were nonexistent. In 1950, production rapidly increased to a peak of 218,000 pounds per year in 1951. Thereafter, however, it decreased similarly as it did in all of Lake Huron, and in 1966 only 2,970 pounds were caught.

Of the other remaining principal species, there has been no scarcity in Saginaw Bay in recent years. Because of economic considerations, the fishing intensity with regard to many species has declined and, hence, apparent catch figures decreased. White and red horse suckers are a good example of this phenomenon. Despite rising abundance of fish, sucker production has decreased from 1,305,000 pounds per year (1930-1934) to just 299,000 pounds per year in 1966. Fishing intensity for suckers has decreased steadily since 1937.

Lake herring demonstrated a similar trend until 1952. Fish production had fallen to 1/3 of the 1930-1934 catch figures. From 1952 on, however, lake herring catches dropped even more dramatically. This may not have been a principal result of decreased fishing intensity but a consequence of the 1952-1954 explosion of alewife populations. In 1966 only trace landings of lake herring were reported.

Production of carp has increased in recent years despite decreases in fishing intensity. The bay populations are so great that they have overridden the declining fishing pressures and now constitute between 30 and 50% of the total catch.

Until the early 1960's, production of yellow perch had been gradually decreasing because of declining fishing pressure. Abundance, however, was increasing. Beginning in about 1963 perch production rose sharply from approximately 278,000 pounds to 1,221,000 pounds in 1966. The increase has been attributed to increased fishing intensity. Fishing pressure increased because of relaxed regulations on perch fishing and, more importantly, the decline in Lake Erie production.

The catfish is the only species in Saginaw Bay for which production, availability, and fishing intensity have been consistently above the 1929-1943 average. There has existed a fairly steady supply and market for catfish in recent years. There appears to be a periodic fluctuation in catfish production. High production of over 300,000 pounds per year was observed in the early 1940's and late 1950's, and low production was observed before 1940, in 1950, and decreasing production 1960-1965. There were 164,000 pounds of catfish landed in 1966.

The only other significant change in production trends has been the gradual increase in chubs. Following the decrease in lake trout, whitefish, and walleyes, the number of chub landings increased from just a trace in 1949 to a peak of 3.2 million pounds in 1961. The chub production has declined since then to 5,000 pounds in 1966. This fluctuation in chub production has similarly been noted in other great lakes.

Overall, the commercial fish industry in Saginaw Bay is today in a very depressed condition, despite attempts to control invading marine species, stop commercial exploitation, and stock desirable fish.

Besides the commercial fishing industry, Saginaw Bay supports an active and diverse year-round sport fishery. Perch and bass are probably the most important species,with pike, catfish, walleye, and carp also important, especially in the shallow, weedy portions of the bay. Rainbow trout have been landed in the outer bay. Recently coho salmon have become important due to an extensive stocking effort in the Au Gres and Tawas Rivers. Numerous other fish are caught for sport in Saginaw Bay tributaries.

Sporadic complaints have come in over the years concerning fish taints. These complaints are rare, however, in recent years. The taints were possibly due to trace organic chemicals originating from the Saginaw River. Positive identification of the exact source is not always possible. Dow Chemical Company of Midland has now taken extreme measures to eliminate the discharges of any organics which might institute such taint problems. Commercial fishermen feel that the taint problems are no longer significant.

APPENDIX A

Persons and Agencies Contacted

Army Corps of Engineers
  - Jack Collis
  - Elihu Jackson

Bureau of Sport Fisheries
  - Ray Argile

Canadian Center for Inland Waters
  - Keith Rogers
  - W. A. Glooschenko

Consumers Power Company
  - Jackson, Michigan

Dow Chemical Company
  - Midland, Michigan

Environmental Protection Agency (Chicago)
  - Don Walgren
  - Bill Frans

Great Lakes Basin Commission
  - Mr. Hall
  - Barb Kollar

Great Lakes Research Division
University of Michigan

International Joint Commission
  - Gary Guenther

Lake Survey Center, Detroit
  - Dr. Pinsak

Michigan Water Resource Commission
  - Biological Division
    - Ron Willson
  - Comprehensive Studies
    - Bill McCraken
    - Fred Morley
  - Industrial Waste Water Division
    - Galen Kilmer
  - Municipal Waste Water Division
    - Thomas Hoogerhyde
    - Michael Smith

Saginaw Midland Water Supply Advisory Board

APPENDIX B

Annotated Bibliography on the Saginaw Bay Basin

Allen, H.E. "Chemical Characteristics of South Central Lake Huron." Great Lakes Research Division, University of Michigan, Ann Arbor. Pub. #11, 1964.

Presentation of the chemical analysis from a 1956 survey of Lake Huron. Including sampling stations at the mouth of Saginaw Bay and along a transect of South Central Lake Huron.

Ayers, John C. "The Currents of Lakes Michigan and Huron." GLR Institute, University of Michigan, Ann Arbor, 1959.

A study of lake currents with only limited mention of Saginaw Bay. Includes an abridgement of the following publication.

Ayers, John C.; Chandler, D.C.; Henson, E.B.; Lauff, G.H.; and Powers, C.F. "Currents and Water Masses of Lake Huron." University of Michigan, GLR Institute, Ann Arbor. Tech. Paper #1, 1956.

A more detailed examination of currents in Lake Huron, although significant attention was placed on Saginaw Bay. Included extensive drift bottle studies. The article was concerned with primarily surface currents.

Batchelder, T.L. "Saginaw Bay Basline Ecological Survey, 1971. Waste Control Dept. Dow Chemical Co., Midland, Michigan, 1973.

A significant limnological study of 29 bay stations carried out in August to September of 1971. Routine chemical analysis was performed on the water including those for D.O., nitrogen and phosphorous compounds, and most major anions and cations. Additional chemical analysis was made on the bottom sediments with special emphasis on heavy metal concentrations. Biological information was also gathered including phytoplankton and benthos investigation. PCB levels were also measured in numerous carp. Unfortunately the information from this report was not available in time to be included in the text.

Beak Consultants. "Biological Survey of Saginaw Bay, 1970." For Consumers Power Company, Jackson, Michigan, January 1971.

A biological survey including sampling of benthos, plankton, fish, macrophytes. Intended to evaluate

impacts of power plant discharges in the vicinity of Saginaw River and Quinacassee.

Beak Consultants. "A Biological Survey of Saginaw Bay, 1971." For Consumers Power Company, Jackson, Michigan, 1972.

A similar study to the 1970 survey except in this survey only benthos and fish were sampled.

Beeton, A.M. "Relationship Between Secchi Disc Readings and Light Penetration in Lake Huron." Trans. Amer. Fish Soc. 87th meeting. Pub. 1958. p. 73-79.

Beeton, A.M.; Smith, S.H.; and Hooper, F.H. "Physical Limnology of Saginaw Bay, Lake Huron." Great Lakes Fishery Commission, Ann Arbor, Michigan, 1967.

Results of a thorough 1956 survey of Saginaw Bay. Included physical and chemical analysis, flushing rates, and transport calculations. Overall, a very well done study.

Bretz, J.H. "Causes of Glacial Lake Stages in Saginaw Basin, Michigan." Journal of Geology, vol. 59, 1951. p. 244-258; p. 137-143.

Discusses the geologic history of the Saginaw Basin area. Not of much use beyond geological interests.

Brinkhurst, R.O. "The Distribution of Aquatic Oligochaetes in Saginaw Bay, Lake Huron." L & O, vol. #12, No. 1, 1967.

A detailed analysis of species distribution of Oligochaetes in Saginaw Bay from a 1956 survey. A good study, however, no profound conclusions could be drawn.

Carr, I.A. "Distribution and Seasonal Movements of Saginaw Bay Fishes." U.S. Fish & Wildlife Services, Pub. #417, April 1962.

Evaluation of a 1956 survey of Saginaw Bay with regards to numbers and species of fish found, where and when. No concrete generalizations were made.

Consumers Power Company. "Investigations of the Terrestrial Biota on the Quinacassee site, Autumn 1972."

A good analysis of the terrestrial environment. It also offered climatology data and limited amounts of bay levels information.

Consumers Power Company. "Biological Survey in the Vicinity of the Quinacassee plant site." Jackson, Michigan, June 1973.

Results of a 1972 survey of the Quinacassee area, examining plankton, benthos, and macrophyte populations. Intended to evaluate the impact of their power plant discharges.

Consumers Power Company. "Consumers Power Company 1971 Water Quality Surveys."

Several temperature surveys done to evaluate the effects of power plant discharges in the vicinity of the Saginaw River.

Consumers Power Company. "Environmental statement related to the construction of Midland Plant Units 1 and 2." U.S. Atomic Energy Commission, March 1972.

An environmental impact statement with regards to the Midland plants and their impact on the Tittabawassee basin.

Canadian Center for Inland Waters. "Limnological Data Report #1." Furlington, Ontario, 1968.

The results from August cruises of Lakes Huron and Superior. Had limited amounts of information on Saginaw Bay.

Dow Chemical Company. "Ecological Survey of the Saginaw River and its major tributaries with special emphasis on the Tittabawassee River." Dow Chemical, Midland Division, Waste Control Dept., 1973.

Overall a good ecological survey of 16 stations in the Saginaw system including 4 on the Saginaw River and 9 within the Tittabawassee River system. Physical and chemical measurements were made including those for solids, alkalinity, specific ions, nutrients and metals. Biological investigations included those for periphyton, macroinvertebrates, and fish.

Dow Chemical Company, Midland Division. Chloride concentration charts of the Saginaw Bay.

These were unevaluated color coded chloride concentration charts of the bay available since 1935 at various times. The only good comprehensive source of chloride information on the bay.

El-Zarka, Salah El-din. "Fluctuations in the populations of yellow perch in Saginaw Bay, Lake Huron." U.S. Dept. Interior, Fish and Wildlife Division, Fish Bul. #151, volume 59, 1959. p. 365-415.

A discussion of growth rate, age composition, size distribution, length-weight ratios, and sex ratios of perch catches from 1929-30 and 1943-55.

Environmental Protection Agency. "STORET Data."

A retrieval of all physical and chemical water quality data for the Saginaw Basin available from the national STORET systems.

Gordon, William G. "Food of the American Smelt in Saginaw Bay, Lake Huron." Transactions of American Fisheries Soc., Vol. 90, No. 4, October 1961. p. 439-443.

A 1956 stomach analysis study of 411 smelt caught in Saginaw Bay.

Great Lakes Water Quality Board. "Great Lakes Water Quality." International Joint Commission, April 1973.

Contained limited information on the nutrient and algal concentrations of Saginaw Bay. Contained isogram plots of concentrations in Lake Huron.

Great Lakes Basin. "Framework Study, Appendix #7 Water Quality, Draft No. 2." Ann Arbor, Michigan, March 1973.

With regards to the Saginaw Basin, it is primarily an evaluation of water quality and discharge treatment recommendations. It contained coliform, transparency, and oxygen isograms charts on Saginaw Bay.

Hile, Ralph. "Fluctuations in Growth and Year-class Strength of the Walleye in Saginaw Bay." U.S. Dept. Interior, Fish and Wildlife Service, Fish Bull. #91, 1954. 38 p.

Over 6000 fish were collected and examined from 1926-30 and 1943 in Saginaw Bay. They were examined for age, length, weight, growth, etc. Appropriate conclusions were drawn.

Hile, Ralph. "The Increase in Abundance of the Yellow Pike Perch in Lakes Huron and Michigan in Relation to the Artificial Propagation of the Species." Trans. Amer. Fisheries Soc., Vol. 66, 1936. p. 143-159.

Hile, Ralph and Howard J. Buetlner. "Fluctuations in the Commercial Fishes of Saginaw Bay 1895-1956." U.S. Dept.

Interior, Fish and Wildlife Division, Report #51, 1959. 38p.

A thorough report on the composition of the commercial fisheries catch since the late 1800's. Figures as well as explanations for increases or declines were given.

Hile, Ralph and Frank W. Jobes. "Age, Growth, and Production of the Yellow Perch of Saginaw Bay." Trans. Amer. Fisheries Soc., 1941. p. 102-122.

A study of 820 fish caught in the period 1929-30. Length-weight ratios, growth, and sex statistics were reported.

Humphreys, C. R. et al. "Shoreline classification of Bay County (Bulletin 21) and Tuscola County (Bulletin 22), Michigan." Dept. Res. Devel. Agricultural Exp. Station, Michigan State University, East Lansing, 1958.

Johnson, James H. "Surface current studies of Saginaw Bay, Lake Huron." U.S. Dept. Interior, Fish and Wildlife Div., Report #287, 1958. 84 p.

A detailed study of the surface currents in Saginaw Bay primarily through the use of drift bottle studies. A valuable study.

Kimball, William and Gordon Bachman. "County and district land use patterns in Michigan." Michigan State University Cooperative Extension Service, 1969.

Contained useful information concerning land usage in the Saginaw Basin. Segmented it into categories such as agricultural, industrial, urban, forested, navigational, recreational, etc.

Michigan State University. "Ecological Survey of the Quinacassee Plant Site." (Dr. L. Gysel, T. Reichard, and L. Reed)

A detailed study of the ecology of the Quinacassee area. Examination of wildlife, topography, and fish. Included a limited environmental impact evaluation of a proposed power plant.

Michigan Stream Control Commission. "Saginaw Valley Report." 1937. 156p.

At the time a very comprehensive study of the bay. Included brine discharge data and valuable chloride concentration charts. Also included color, turbidity, and odor information.

Michigan Water Resources Commission. "Report on Bacteriological Quality of Michigan Surface Waters Along the Great Lakes Coastline."

Extensive WRC data on the coliform concentrations at various stations within the Saginaw Basin.

Michigan Water Resources Commission, Department of Natural Resources, Lansing, Michigan. Biologic Studies.

The following studies are typically only a few pages in volume and represented very limited sampling. They are listed here, without annotation, in alphabetical order according to their major receiving watershed.

"Taint studies on Coho Salmon Returning to the Cass River, Fall 1972."

"Biological Investigations of Hughes and Lake Drains and Brent Run, July 11 and October 16, 1972." Flint River.

"Biologic Investigations of Thread Creek, Flint, Michigan, July 13, 1972."

"Biological Investigations on Gilkey Creek, Flint, Michigan, August 22, 1969 and July 11 and 13, 1972."

"Biological Investigations of Carmen Creek,Flint, Michigan, July 13, 1972."

"A Continuous Flow Bioassay and Cage Fish Study of Fisher Body Coldwater Road Plant Effluent, Flint, Michigan, November 27 and December 4, 1972."

"A Continuous Flow Bioassay of the Hickory Street Storm Sewer Discharge, Flint, Michigan, December 11-15, 1972."

"Biologic Survey of the Pine River in the Vicinity of Alma and St. Louis, 1967 and 1970."

"Biologic Survey of the Pine River above Alma to Determine the Effects of Pollution. May 31, 1955."

"Continuous Flow Bioassay of the Total-Leonard Refinery, Alma, Michigan. October 9-13, 1972." Pine River.

"Biologic Investigations of C. K. Eddy Creek, West Branch, Michigan. August 1, 1972." West Branch of Rifle River.

"Biologic Field Studies Conducted on Sebewaing Bay, Fall, 1970."

"Sebewaing Bay, Fish Mortality, March 28, 1957."

"A Caged Fish Study on Toxicity of Intermittently Chlorinated Condensor Cooling Waters at Consumers Power Company's J. C. Weadock Power Plant, Essexville, Michigan. December 6-10, 1971."

"Report on the Fish Mortalities Observed at Kearn-Weadock Power Plant During Week of December 6-10, 1971."

"Fish Off-flavor Problems in Saginaw Bay."

"Caged Rainbow Trout Taint Studies in the Saginaw River Watershed October-November 1972."

"Taste Test of Fish from Saginaw Bay, February 27-28, 1968."

"Fish Tainting Problems in Saginaw Bay, Winter of 1962-1963."

"Taste Test of Fish from Saginaw Bay, May 12, 1965."

"Taste Test of Fish from Wild Fowl Bay Area of Saginaw Bay, January 26, 1968."

"Waterfowl Mortality Sebewaing Fish Point Area, late August-September 1962."

"Caged Rainbow Trout Taint Studies in Saginaw River Watershed October-November 1972."

"Report on Fish Mortality in the Tittabawassee River below Dow Chemical, July 27, 1971."

Michigan WRC, DNR

The following are comprehensive studies performed within the Saginaw Bay Basin. They are again listed alphabetically according to their receiving stream or bay.

"Oxygen Relationships of Cass River, 1960."

A study of the Cass River between Frankenmuth and Bridgeport describing the polluting sources, hydrology, geology, BOD, D.O., and oxygenation and deoxygenation relationships.

"Oxygen Relationships in the Cass River."

A 1968-1970 study very similar to the 1960 study. This report emphasized the Cass River downstream from Caro, Michigan.

"Chippewa River Water Quality Study."

A 1968 study of the river in the vicinity of Mt. Pleasant. It included discussions of hydrology, geomorphology, land use, waste discharges, and pollutional sources, and surveys of D.O., BOD, coliform densities, nutrient concentrations, etc.

"Water Resource Conditions and Uses in the Flint River Basin."

A 1956 report including information on population, hydrology, and water uses, such as recreation, navigation, water supply, power, etc.

"Water Quality Study, Flint River Tributaries."

A 1970 report on the major tributaries to the Flint River, Gilkey Creek, Swartz Creek, Carinan Creek, and Thread Creek. It includes discharge information as well as physical, chemical, and biological water quality data.

"Water Quality Study of the Flint River."

A 1970 report describing sources of waste, hydrologic conditions, dissolved oxygen and BOD observations, bacterial densities, nutrient concentrations and limited biologic investigations.

"Pine River Water Quality Study."

A 1967-1970 survey of the Pine River documenting geographical considerations, waste discharge information, and water quality data. Measurements were taken of D.O., BOD, nutrient concentrations, various physical and chemical parameters, and coliform.

"Results of a study of the Bottom Fauna of Saginaw Bay, July 25 and 26, 1953."

> A survey of 19 stations in Saginaw Bay, documenting benthic fauna. A breakdown was given of percentages of clean facultative and tolerant species.

"Results of a Biologic Survey of Saginaw Bay, July 16, 17, 1954."

> Fifteen bay stations were sampled for benthic fauna, species composition was evaluated.

"Results of a Biologic Survey of Saginaw Bay, June 24, 1955."

> Nineteen stations were sampled for benthic fauna. Comparative analysis was made to the 1954 and 1953 studies.

"Saginaw Bay Biologic Survey, July-August 1965."

> Forty-three stations were sampled for bottom organisms. Species composition and comparisons to past studies were reported. Overall a thorough study.

"Water Quality Study of the Saginaw River, July-October 1965."

> A report detailing the hydrology of the river, its sources of waste, oxygen profiles and predictions, various physical and chemical parameters, and limited biological investigations.

"Biological Survey of Sebewaing Bay, September 1970-May 1971."

> Included investigations of fish populations, benthic animals, artificial substrate studies, sediments, and sources of waste to the bay.

"Water Resources Conditions and Uses in the Shiawassee River Basin."

> A 1963 report including discussions of geography, hydrology, water use and management, floods and flood control and low flow augmentation.

"Oxygen Relationships in the Shiawassee River."

A 1968 study detailing basin descriptions, waste assimilation of the river, effects of pollutants, and deoxygenation relationships.

"Water Resource Conditions and Uses in the Tittabawassee River Basin."

A 1960 report dealing primarily with land and water uses within the basin.

"Biologic Survey of the Tittabawassee River 1971-1972."

A thorough study of the biologic communities of the Tittabawassee. Examines fish, benthos, phytoplankton, periphyton, rooted aquatics, and toxic materials concentrations.

Michigan WRC DNR Industrial Waste Water Surveys.

Generally a one or two day survey of an industrial discharger. The reports are typically short. They are listed alphabetically according to the receiving tributary.

Nestles Co. Inc. June 6-7, 12-13, 1972: Cass River.
Michigan Sugar Co. November 13-15, 1972: Cass River.
Ferro Manufacturing Corp. June 12-14, 1973: Chippewa River.
Metal Dynamics Inc. June 6 and 13, 1972: Flint River.
Anderson-Safeway Guardrail. August 28-30, 1972: Flint River.
Buick Motor Division. June 13-14, 1972: Flint River.
Chevrolet Engine Plant. May 2, June 6-8, 1972: Flint River.
Fisher Body Div. GMC. May 2, June 6-8, 1972: Flint River.
Fisher Body Div. GMC. August 28-30, 1972: Flint River.
General Motors Parts Div. April 19-21, 1972: Flint River.
Kraft Foods. May 17, 18, 19, 1972: Pinconning River.
Magline Corp. April 11-12, 1972: Pinconning River.
Magline Corp. March 27-28, 1968: Pinconning River.
Alma Travelodge. November 20, 21, 22, 1972: Pine River.
Michigan Chemical Co. August 28-September 1, 1967: Pine River.
Michigan Chemical Co. September 8-10, 1970: Pine River.
Chevrolet Metal Casting. April 3-5, 1972: Saginaw River.
Monitor Sugar Co. February 11, 12, 16, 17, 1970: Saginaw River.

Monitor Sugar Co. December 11-12, 1968: Saginaw River.
Michigan Sugar Co. October 21-24, 1968: Saginaw River.
Michigan Sugar Co. December 20, 1966: Saginaw River.
Chevrolet Parts Div. GMC. November 30-December 1, 1971: Saginaw River.
Michigan Producers Dairy. August 20-21, 1969: Sebewaing River.
Michigan Sugar Co. October 12-15, 1970: Sebewaing River.
Michigan Sugar Co. January 6-8, 1970: Sebewaing River.
Ford Autolite Division. December 7-9, 1971: Shiawassee River.
American Record Pressing Co. December 8-9, 1971: Shiawassee River.
Dow Chemical Co. April 16-18, 1968: Tittabawassee River.

Michigan WRC DNR. "Interim Water Quality Management Plan for the Saginaw River and Huron Western Shore Minor Basins." April 1971.

A report primarily concerned with resource management and planning. It did include hydrologic, geographic, and water quality information. Described in detail land usage and population patterns.

Michigan WRC DNR. Miscellaneous Water Quality Reports. Listing alphabetically according to major tributaries.

"Effects of Earl Johnson Cattle Feedlot on Water Quality." April 10 and 19, 1969. Flint River.

"PCB's in Saginaw River Basin." January 1973.

"A survey of chlorine concentrations in the J. C. Weadock Power Plant Discharge." Saginaw River.

"Water Temperature Survey of the Saginaw River Mouth."

"Report of Caustic Spill into the Tittabawassee River by Dow Chemical Company, August 13, 1971." Tittabawassee River.

Michigan WRC DNR: Monthly operating reports on discharges to the Saginaw Basin.

A computer listing of all the direct dischargers in the basin and the discharge stipulations for which they must comply and report on monthly according to the NPDES system.

Michigan WRC DNR: Municipal Dischargers.

A listing for the Bureau of Water Management enumerating all municipal dischargers and the extent of WRC's records concerning their effluent.

Michigan DNR, WRC. "The Water Resources of Lower Lake Huron Drainage Basin." May 1968.

An overview of the regions water uses. Hydrology, geology, water and land usage and general water quality were discussed. Various rivers were discussed individually with regard to water quality.

Michigan DNR WRC. "Water Resource Uses Present and Prospective for Lake Huron."

An overview of the existing water resources and their uses. Basic problems were identified and water quality standards were proposed. Plans for implementation were also included.

Michigan DNR WRC. "Water Quality Monitoring Program of Michigan Waters along the Great Lakes Coastline." 1963-1969.

A complete listing of the water quality measurements made on the Great Lakes tributaries. Included physical, chemical, and hydrological data.

Shneider, J. C., Hooper, F. H. and Beeton, A. M. "The Distribution and Abundance of Benthic Fauna in Saginaw Bay, Lake Huron." Proc. 12th Conference on Great Lakes Research, 1969. p. 80-90.

A very good analysis of a 1956 survey of benthic resources of the bay. Species composition, distribution, and abundance are discussed and compared with other benthic studies.

Schuytema, G. S., and Powers, R. E. "The Distribution of Benthic Fauna in Lake Huron." GLRD, University of Michigan, Pub. #15, 1966. p. 155-163.

Presents the results of a 1965 survey of Lake Huron of which 24 stations were in Saginaw Bay. Identified all species found. Emphasized oligochaete and amphipod distribution in Saginaw Bay.

Tarrant, William J. "Water Quality Review with a History of Water Supplies." Prepared for Saginaw Midland Water System

Research Advisory Board, 1972.

A collection of maps, charts, and papers concerned with the Saginaw Midland water supply and uses.

Teter, Harold E. "The Bottom Fauna of Lake Huron." Trans. Amer. Fisheries Soc. Vol. 89 (2), 1960. p. 193-197.

The examination of 63 bottom samples from 1952 and 1956 surveys of Lake Huron. Included only the very outer limits of Saginaw Bay.

Tharratt, Robert C. "Food of Yellow Perch in Saginaw Bay, Lake Huron." Trans. Amer. Fisheries Soc. Vol 88, 1959. p. 330-331.

Stomach analyses were performed on 241 fish from 4 stations in Saginaw Bay.

University of Michigan, Great Lakes Research Division. "Limnological Surveys of Lakes Michigan, Superior, Huron, and Erie." Pub. #17, 1973.

A wide encompassing survey of four of the Great Lakes. It included six stations in Saginaw Bay and often valuable information on phytoplankton and zooplankton.

U. S. Army Corps of Engineers. "Saginaw River." A House Document from February 23, 1956, 84th Congress, 2nd session.

Primarily concerned with flood and navigational problems within the Saginaw River basin. Did not address itself to water quality conditions.

U. S. Army Corps of Engineers. "Preliminary Examination Report on Property Damage on the Great Lakes Resulting from Changes in Lake Levels." 1952.

U. S. Army Corps of Engineers. "Summary of Environmental Considerations, Great Lakes-St. Lawrence Seaway Navigation Season Extension, Waste Heat Utilization Demonstration." U. S. Army Corps of Engineers, District of Detroit, Michigan, 1973.

A report dealing primarily with the environmental impacts that might precipitate if the ice-free navigational season was extended through the use of power plant thermal discharges. The navigation program is designed for the St. Lawrence-Great Lakes system but the demonstrations included only a small area in the Saginaw Bay-Saginaw River system. The environmental considerations were usually qualitative, general, and brief in content. The report also included alternatives and a brief description of the Saginaw environment.

U. S. Dept. of the Interior. "National Estuary Study Vol. 3." Fish and Wildlife Service, 1970.

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U. S. Dept. of the Interior, Bureau of Outdoor Recreation. "Preliminary, Water Oriented Outdoor Recreation, Lake Huron Basin." October 1967.

Giver an overview of the basin environment and uses emphasizing water supply and water quality effects on recreational uses.

U. S. Dept. of the Interior, Fish and Wildlife Service. "Fish and Wildlife as Related to Water Quality of the Lake Huron Basin." 1969.

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U. S. Dept. of the Interior Geologic Survey. "Water Resources Data for Michigan. Part 1: Surface Water Records, Part 2: Water Quality Records." 1970.

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Velz, Clarence J., and Gannon, John J. "Drought Flow Characteristics of Michigan Streams" Dept. of Environmental Health, University of Michigan, 1960.

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